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IRON AND STEEL INSTITUTE

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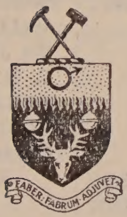
EDITED BY

GEORGE C. LLOYD

Secretary



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PREFACE.

The present volume of the *Journal of the Iron and Steel Institute* comprises the minutes of the proceedings at the Autumn Meeting of the Institute, held in the City of York in September last; reprints of the papers presented on that occasion, and the discussion and correspondence to which they gave rise. There is likewise included an account of the Visits and Excursions to places of interest which were made by members on the conclusion of the Meeting, and obituary notices of prominent members who have died recently.

In Section II. will be found the usual Notes on the progress of the iron and steel industries at home and abroad, consisting of abstracts of the principal articles which have appeared in the British and foreign technical press, with a bibliography of the more important books and reports published during the past six months.

28 Victoria Street, London, S.W. 1.
December 31, 1922

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THE

IRON AND STEEL INSTITUTE.

SECTION I.

MINUTES OF PROCEEDINGS.

YORK MEETING.

The Autumn Meeting of the Iron and Steel Institute was opened on the morning of Tuesday, September 5, 1922, at the Tempest Anderson Hall in the Museum of the Yorkshire Philosophical Society, York, under the Presidency of Mr. Francis Samuelson.

In the unavoidable absence of the Lord Mayor of York, Alderman E. Walker attended on his behalf to welcome the members to York, and Mr. R. L. Wedgwood, C.B., C.M.G., also extended a welcome to the members on behalf of the Chairman and Directors of the North Eastern Railway Company.

Welcome to the Institute.

Alderman Walker said he had been deputed to offer the members of the Iron and Steel Institute a welcome to the ancient City of York. He quite realised that he was addressing experts in science. During the long years of the war experts of all kinds had achieved a tremendous task in hastening the end of the war and bringing it to a successful issue. Therefore it was to them, as men of science, that the nation owed a deep debt of gratitude, and he bade them a hearty welcome to York, with the traditions of which they were, no doubt, well acquainted. It was gratifying that York had been selected as the venue of the meeting, and he trusted their deliberations would tend to improve the great art they were connected with in regard to the iron and steel industries. He understood that they were not only producers of material but that they furthered scientific investigations for the improvement in the methods of iron and steel production. It was perhaps equally important in those troubled days to apply themselves to the great question of how they were to improve trade, and how to regain the markets they had lost. To him it seemed that the only way was for employer and employees alike to present a united front, and to join hands to repair the losses of their industry. They had the works, they had the material, and they had the labour—the finest in the world. They were the producers for the whole world, and it was therefore their duty to do all they possibly could to increase their output, and to regain that which had been lost owing to the stress of the late war. He wished them a hearty welcome to the ancient City of York.

Mr. R. L. Wedgwood, C.B.E., General Manager of the North Eastern Railway Company, said that Alderman Walker had expressed to them a welcome on behalf of the City of York, an ancient and honourable Corporation—so ancient that in comparison the North Eastern Railway was a mushroom growth. To him had fallen the honour of welcoming them to the headquarters of that Railway Company. There was present amongst them one of the Directors of his Railway Company who would have been far more capable of discharging the pleasant duty. He (Mr. Wedgwood) understood, however, that Sir Hugh Bell was attending the meeting in his capacity as a member of the Council of the Institute, of which he had also been President. It was hardly likely, therefore, that he would wish to propose a vote of welcome to himself. The Iron and Steel Institute needed no introduction to the capital of the County of York or to the North Eastern Railway, because Yorkshire might be said to be its home. The Chairman was a Yorkshireman, the Hon. Treasurer was a Yorkshireman by virtue of long residence, and the list of Past-Presidents of the Institute contained the names of many Yorkshiremen. If Sheffield, Leeds, and Middlesbrough could not find themselves at home in York he did not know where they could. Nor did the North Eastern Railway need any introduction to them. Many of them knew it only too well. They knew its virtues and its faults, and the faults he felt bound to say would have been more numerous had it not been for the loyal way in which the iron and steel interests had dealt with it. As a railway it was directed, managed, and run by iron, steel, and their cousin coal. It was, in fact, the hewer of wood and the drawer of water of those great interests; indeed, they had but to say to the Railway Company "do this" and it was done! The North Eastern Railway carried more of the raw materials for the manufacture of iron and steel products than any other railway in the country. It was dependent upon the prosperity of the iron and steel trade. They were, so to speak, partners in business, and he hoped they would agree that in the past his Company had endeavoured adequately to fill that position. At the same time he was aware that, though partners, there were times when there had been differences of opinion. Such differences arose in any business in which there were partners and would, no doubt, continue to arise, but he would like to assure the members of the Iron and Steel Institute that the interests of the iron and steel trade were also the interests of the Railway Company. Looking through the agenda, he confessed he came to the meeting with at first a certain amount of fear, because he had expected such questions as demurrages and railway charges to come up for discussion. That fear was, however, dispelled when he noticed that one of the papers presented for discussion dealt with the subject of the diminution of lag, and that after all there could be no question of railway rates—or speeds—involved. It was with all the greater pleasure that he was able therefore to extend to them a welcome on behalf of the North Eastern Railway Company.

The PRESIDENT, in acknowledging the welcome, said they much regretted that the Lord Mayor had been unable to be present, and they were very grateful to Alderman Walker for the kind welcome he had accorded them. The Iron and Steel Institute was fortunate in being able to meet in that beautiful and ancient City of York, and they could not have found a better place for the actual sessions than the building in which they were met. Its amenities were very great and it was very central and easily reached. He also thanked the North Eastern Railway Company and Mr. Wedgwood for the kindly welcome they had given, and for the very practical help they had extended as regards their excursions. They were alive, as Mr. Wedgwood had pointed out, to the interdependence of their interests. What was good for the Railway Company was good for them, and what was good for them was good for the Railway Company. They should always remember that when their interests clashed. They ought not to clash, because if they wanted more than their share of the partnership the Railway Company could not carry on, and if the Railway Company wanted more than their fair share the industry could not bear it, and would not be able to give them the traffic upon which they depended. He desired to thank the people of York and the North Eastern Railway Company for the welcome which had been extended to them.

The minutes of the previous meeting, held in London on May 4 and 5, were taken as read and approved, after which the President gave notice on behalf of the Council of a resolution in regard to an alteration of Bye-Law 10, dealing with the method of procedure in the election of a President.

That resolution was that the first two lines of the present Bye-Law 10, which read:

> "The President shall be elected for two years and shall not be eligible for re-election until after an interval,"

be altered to read as follows:

> "The President shall be elected for one year,"

and that the words, "and shall not be eligible for re-election until after an interval," be omitted.

The President explained that the alteration contemplated, whilst having the effect of electing the President for one year, would not in any way tie the hands of the Institute should it be desired to re-elect the President for a further term of office, and should the President be willing to serve for such further period. The resolution would be brought forward at the Annual Meeting in May 1923.

The SECRETARY submitted the names of the Vice-Presidents and Members of Council who, in accordance with Bye-Law 10, were due to retire at the Annual Meeting in 1923, but were eligible for re-election. These were:

Vice-Presidents: Mr. C. J. Bagley; Sir William H. Ellis, G.B.E.; Mr. M. Mannaberg.

Members of Council: Mr. F. W. Gilbertson; Mr. E. H. Saniter; Mr. John Craig, C.B.E.; Professor H. Le Chatelier; Sir John S. Randles.

APPOINTMENT OF SCRUTINEERS.

Mr. C. H. Ridsdale (Middlesbrough) and Mr. C. A. Ablett (London) were appointed scrutineers of the ballot for the election of new members and associates, and later reported that the following twenty-seven candidates for membership had been duly elected:

MEMBERS.

NAME.	ADDRESS.	PROPOSERS.
Barreiro, Luis	Gran Via 44, 1°, Bilbao	H. Jeans, H. Spence Thomas, W. F. Cheesewright.
Bates, Alfred Ralph	Bengeworth, Wellingborough	W. Ralph Bates, E. H. Saniter, W. A. Seaman.
Bell, Gerald Spencer, B.A. Oxon.	Hillside, South Park, Lincoln	J. E. Stead, E. Adamson, T. Baker.
Cook, Earnshaw, B.S.	Towson, Maryland, U.S.A.	H. Fay, V. O. Homerberg.
Crane, Charles Richard	836 South Michigan Avenue, Chicago, Ill., U.S.A.	J. A. Mathews, E. L. French, H. J. Stagg.
Davies, James Arthur	Hylton Dene, Parkfield Road, Wolverhampton	A. J. While, A. Pool, A. Wright.
Goodwin, John Thomas	The Red House, Old Whittington, Chesterfield	R. J. Davy, J. W. Percival, E. Adamson.
Gregg, Wells K., B.S.	562 Reed Street, Milwaukee, Wis., U.S.A.	F. P. Gilligan, J. J. Curran, A. H. d'Arcambal.
Jenkins, William George, B.Sc.	Glenavon, Station Road, Harlington, Middlesex	A. A. Read, M. Moses, Gethin Jones.
Keenan, John Lawrence	Messrs. The Tata Iron and Steel Co., Jamshedpur, India	C. A. Alexander, R. Mather, R. Knowles.

NAME.	ADDRESS.	PROPOSERS.
Martyn, Philip Lindsay	Steel Company of Australia, Brunswick, Melbourne	C. H. Desch, F. C. Thompson, H. O'Neill.
Moore, Leonard S.	"Clarach," Woodfield Avenue, Penn, Worcestershire	A. J. While, A. Pool, A. Wright.
Murakami, Takejiro	Tohoku Imperial University, Sendai, Japan	H. C. H. Carpenter, W. H. Merrett.
Noden, George A.	P.O. Box 48, Union Steel Corporation, Vereeniging, Transvaal, South Africa	J. O. Arnold.
Oldale, Harry, B.Met. (Sheffield)	Tata Iron and Steel Co., Jamshedpur, India	T. G. Arnold, C. H. Desch, F. C. Thompson.
Pain, Douglas W.	Elm Bank, Kettering	W. Ralph Bates, E. H. Saniter, W. A. Seaman.
Parks, Philip Barron	82 Cammell Road, Firth Park, Sheffield	H. Brearley, A. W. Brearley, J. H. G. Monypenny.
Penny, Geoffrey James	c/o Broken Hill Proprietary Co., Steel Works, Newcastle, Australia	D. Baker, W. L. Cleland, E. Lewis.
Potts, Ernest	23 Palmer Street, Chippenham, Wiltshire	C. O. Bannister, T. F. Hardyman, E. F. Law.
Proctor, Ernest Arthur	Tata Iron and Steel Co., Jamshedpur, India	F. Somers, H. A. Davies, T. E. Freeston.
Reinartz, L. F.	1020 Arlington Avenue, Middletown, Ohio, U.S.A.	J. H. Nead, R. O. Griffis, F. Crabtree.
Sanders, Thomas Henry	82 Victoria Street, London, S.W. 1	G. Cawley, H. Brearley, M. R. Mainprice.
Sokehill, Ben	Burnside, Waschbank, Natal, S. Africa	F. Chambers, P. N. Hambly, W. F. Cheesewright.
Thompson, James Lovelace	Monk Bridge Iron and Steel Works, Leeds	Illtyd Williams, The Hon. R. D. Kitson, E. Jeffreys.
Walters, Owen	Netherley, Pietermaritzburg, Natal, S. Africa	F. Chambers, P. N. Hambly, W. F. Cheesewright
Warburton, Thomas Henry	Monk Bridge Iron and Steel Works, Leeds	Illtyd Williams, The Hon. R. D. Kitson, E. Jeffreys.
Woodside, William P.	The Studebaker Corporation, Detroit, Mich., U.S.A.	J. W. Weitzenkorn, G. W. Sargent, H. G. Kiefer.

The morning session of Tuesday, September 5, was devoted to the reading of a paper by Mr. A. K. Reese on "The Bases of Modern Blast-Furnace Practice." The remaining papers, which were read and discussed on the afternoon of Tuesday the 5th and the morning of Wednesday the 6th, were, in their order of reading, as follows:

C. W. H. Holmes, "An Investigation on the Factors influencing the Grain and Bond in Moulding Sands."
J. H. Whiteley, "The Diminution of Lag at Ar1 through Deformation."
L. E. Benson, "Nitrogenisation of Iron and Steel by Sodium Nitrate."
J. H. S. Dickenson, "Some Experiments on the Flow of Steels at a Low Red Heat, with a Note on the Scaling of Heated Steels."
H. K. Ogilvie, "Practical Notes on the Manufacture and Treatment of High-Speed Steel."
L. Aitchison and G. R. Woodvine, "The Changes of Volume of Steels during Heat Treatment."

The following two papers were taken as read:

E. D. Campbell, "A Brinell Machine Attachment for Use with Small Specimens."
E. D. Campbell and E. R. Johnson, "A Preliminary Magnetic Study of some Heat-Treated Carbon Steels."

The President moved a vote of thanks to the President and Council of the Yorkshire Philosophical Society and to Dr. Collinge, the Keeper of the Museum, for their kindness in allowing the Institute to have the use of the rooms. The Institute, he said, was greatly privileged in having such a very excellent place in which to meet. It was a place that was not only ideal in a practical way, but it had the additional advantage of being situated in such beautiful grounds. Having referred to the historical monuments of York, which they met with at every turn, the President said it was not often that they found themselves in such thoroughly genial surroundings, quite apart from all the matters in which they were technically and professionally interested. He hoped Dr. Collinge would convey to the Council of his Society their very sincere thanks for the very kind way in which they had put all their resources at the disposal of the Institute.

Dr. W. E. Collinge, speaking on behalf of the Council of the Yorkshire Philosophical Society, said they were very pleased indeed to have the Institute meet in their rooms, and personally he hoped it would not be the last time they would have the pleasure of entertaining them. It had been a source of great satisfaction to his Council to know that they could accommodate the members of the Institute, and he hoped it had been a pleasant visit to them and that everything had been done for them in the way of accommodation and other facilities afforded them.

Mr. LAMBERTON said there was one little duty to perform before the meeting dispersed, and that was to express their warm thanks to the President for the very capable manner in which he had conducted the meetings. He was sure the members would agree with him in saying that they had been very fortunate in having Mr. Samuelson as President. His conduct in the chair called from all of them an expression of their warmest appreciation of his kindness.

The PRESIDENT formally thanked the members, this concluding the sessions for the reading and discussion of papers.

1922, No. II.; Vol. CVI. Autumn Meeting, Sept. 5-6.

Iron and Steel Institute.

THE BASES OF MODERN BLAST-FURNACE PRACTICE.

BY A. K. REESE, B.S., E.M., M.I.MECH.E. (CARDIFF).

IN the author's evidence before the Iron and Steel Industries Committee of the Board of Trade in 1918, he mentioned certain important features as constituting the difference between modern blast-furnace practice and such practice as is generally prevalent in Great Britain. He proposes in this paper to elucidate the reasons for those observations by outlining the bases upon which modern blast-furnace practice has been built up, and demonstrating wherein those bases supply the logical arguments for their adoption, which would lead to very desirable improvements in results, both as respects output and economy, in pig iron production in localities where the older practice is still in vogue.

There are many factors entering into this subject, each of which is more or less dependent upon the others. They may be divided under four major headings, which may be called the prime factors in modern blast-furnace practice.

Before discussing these prime factors in detail, it might be as well to consider the objects which modern blast-furnace practice seeks to obtain. That practice is distinctly the result of evolutionary progress, the modern phase dating from 1894, when James Gayley introduced the low bosh at Braddock, Pa.—up to the present, the era of the large hearth diameter and steep bosh angle.

There are three principal objects in all blast-furnace practice ranking in importance in the following order—quality, economy, and quantity. The first is essential. The second is commercially of great importance. The third is highly desirable, particularly in its bearing upon the second. No. 1 may be obtained independently of the other two. No. 2 may be obtained, to a degree, independently of No. 3. No. 3 is, to a degree, subject to Nos. 1

and 2. In all blast-furnaces one of these objects has been the limiting factor in the attainment of the others.

The object sought through the application of so-called modern practice may be described thus:

> Consistent with quality to produce the greatest possible economical quantity, and as any material increase in quantity has a direct and favourable bearing upon economy this description of the object of modern blast-furnace practice may be condensed to—*the attainment of the greatest possible quantity consistent with quality.*

The degree to which this object has been attained in certain localities, in comparatively recent years, resulting in normal economical outputs of from 400 tons to 600 tons per twenty-four hours, is well known, and demonstrates the great commercial advantage to be obtained by the adoption of the principles and methods by which it has been attained, in those other localities which up to the present have not yet fully adopted them.

There may be, and doubtless are, some makers who are still of opinion that with their particular materials the principles and methods of so-called modern blast-furnace practice are not applicable. It is with the hope of convincing them, and of strengthening the growing belief of others, that the author has undertaken this paper, for it is his firm conviction that those principles and methods are adaptable to any iron-bearing materials which are workable in a blast-furnace, subject, of course, to suitable fuel and flux being obtainable within even a wide degree of quality, and subject, likewise, to a minimum degree of variation in that quality for any individual operation. He feels convinced that their adoption will lead to so great an advantage as to constitute almost a revolution in the pig iron industry in those localities where they have not hitherto been applied.

The four prime factors above referred to are:

I. Preparation of Materials.
II. Furnace Design.
III. Auxiliary Equipment.
IV. Method of Operation.

I. Preparation of Materials.

That the mechanical and physical conditions of the materials charged into a blast-furnace have a most important bearing upon its successful and satisfactory operation, affecting both its operative conditions and the economy of the results obtained therefrom, is a fact which no blast-furnace operator is likely to dispute, but while it is true of any blast-furnace it is particularly true in its bearing upon the operation of the modern blast-furnace. One of the essential conditions of satisfactory operation is that there shall be as nearly as possible uniformity of chemical reactions, and of physical movement of the materials throughout the whole cross-section in every zone of the furnace. Two elements are required to obtain this in theoretic perfection, namely, perfect uniformity in the size and density of the materials charged, and a sufficient blast volume to produce the condition of a plenum throughout the whole furnace interior. While it is, of course, impracticable to obtain for blast-furnace use materials of perfectly uniform size and density in each of the three classes of materials used in pig-iron smelting—fuel, flux, and ore—it is practicable to approximate to a degree to that condition by the use of proper means for their preparation.

It is obvious that the feature which most directly bears upon the essential condition above mentioned is that of distribution, and in order to obtain as nearly as practicable uniformity of distribution such preparation as will give as nearly as practicable uniformity of size must be resorted to. For reasons which will be referred to later, uniformity of size only is not, however, sufficient, for example, uniformly large size, while giving uniformity of distribution, would be detrimental to economical operation. The preparation of materials must be in the direction of uniformly small size

Fuel (*Coke*).—While this principle is much more important in its application to the ore and flux than to the fuel, it also applies, to a degree, to the latter. As rapidity of action is largely dependent upon rapidity of combustion of the fuel, it is desirable that the fuel should not be charged in lumps of excessive size, and preferably should not exceed 4 inches to 6 inches. This is, of course, assuming that the coke is of proper physical condition. It may be said here that the physical quality and chemical purity of coke for blast-furnace use are of the greatest importance. It should be strong but of not great density, and as low as possible in ash and sulphur. There is nothing which more greatly interferes with the regular and economical operation of a blast-furnace than soft, friable, or high ash coke, as everyone connected with the industry has experienced during late years under the conditions existing during, and for some time after, the late war. The disadvantage of high sulphur in the coke need not be emphasised.

The coke as charged into the furnace should be thoroughly screened to free it from smalls, commonly known as breeze, and should be of sufficient strength to prevent the excessive formation of smalls in the furnace through the crushing effect of the burden. The strength should not, however, be of the kind which is produced by great density which destroys the cellular structure. A dense coke burns slowly, and is, therefore, inimical to rapid combustion, which is necessary for fast driving, whereas cellular structure permits the heat and the agents of combustion to penetrate readily to the interior of the lumps, thus facilitating combustion. On the other hand a very open cellular structure produced at the expense of strength is equally to be avoided as tending to produce smalls through its lack of resistance to crushing by the weight it has to bear, and abrasion by its movement in the furnace. Such a fuel is also subject to excessive waste in the upper regions of the furnace before it reaches the zone of its usefulness, owing to the greatly increased reaction upon it of the CO_2 in the gases—$CO_2 + C = 2CO$. It is, therefore, of the greatest importance, in modern blast-furnace practice, that coke-makers should give the greatest possible attention to the production of a coke combining these two essential features—strength and porosity. There are a number of factors entering into this problem of blast-furnace coke making, by the careful study of which the makers may arrive at the production of coke having the desired physical properties described above. Some of these are the coal mixture, the mechanical condition of the coal as charged and its compactness in the oven, the oven temperature, the rate of carbonisation, and uniformity of coking action throughout the coking chamber. It would seem hardly necessary to mention the great importance of chemical purity in the coke, as naturally the higher its carbon content the greater its efficiency. It is surprising, however, how much coke is produced with high ash and sulphur content for blast-furnace use; in many cases, undoubtedly, the result of insufficient or inefficient washing of the coal, or insufficient attention to the selection of the coal for the production of blast-furnace coke. Care in selection and efficient washing of coal for coke production are, therefore, of very great importance in their bearing upon economical blast-furnace operations, and every possible effort should be made by blast-furnace owners to induce coke-makers to meet their requirements as to mechanical, physical, and chemical quality. It is the carbon which does the work in the furnace, and every decrease in the percentage of ash increases the available carbon and tends in other ways towards a higher degree of efficiency. In addition to the higher fuel value of low ash coke, it is lighter in weight, requires less limestone for fluxing the ash, and a lower amount of the fuel charged is required for forming and melting the slag produced from the coke ash. It is estimated that the formation and melting of blast-furnace slag requires approximately 25 per cent. of its weight in fuel, therefore, for every hundredweight of slag produced from coke ash ¼ cwt. of fuel is lost so far as the smelting of iron ore—the primary object of the blast-furnace process—is concerned.

Iron Ore.—From the standpoint of preparation, the iron ore is the most important of all the materials charged into the blast-furnace, owing to the extremes in mechanical condition, from fines to large lumps, in which most iron ores are received from the mines, and the great variety of physical characteristics in different ores. The operation of the blast-furnace is much more usually affected, for good or ill, by the mechanical condition of the iron ore than that of either fuel or flux. It is, therefore, of prime importance that this condition should receive very careful attention, and whatever steps are necessary should be taken, in the way of preparation, to convert it to that condition—or as near to it as is practicable—as will insure the most beneficial effect upon the furnace operation.

There are two principal features directly affected by the condition of the iron ore, both bearing upon the rate of production and upon economy. These are reducibility and distribution. The degree of reducibility of an iron ore depends primarily upon its density, a characteristic which in itself is not readily altered, except with dense ores containing high percentages of protoxide of iron (magnetite), the reducibility of which may be increased by subjecting them to a roasting process in an oxidising atmosphere, thus converting the protoxide to peroxide of iron.

Rough Ores.—The rate of reduction in the furnace may, however, be materially increased for any particular ore containing lumps, whatever its degree of density, by increasing the surface area exposed to the action of the reducing agents. The obvious method of attaining this increase in surface area is by breaking the lumps into a number of smaller pieces. The extent to which this operation may be carried is, of course, limited by the cost of breaking the ore (a commercial consideration), and the tendency of any particular ore to produce an excessive proportion of fines in the breaking. The latter tendency, however, really does not exist to any considerable extent in ores whose condition allows of their being broken at all, for whatever smalls may be produced in the breaking are usually of sufficient size not to be classed as fines, and may, therefore, be safely charged into the furnace with the larger products of the breaking operation.

The increase in the rate of reduction obtained by thus increasing the surface area exposed to the agents of reduction in the furnace, has, in addition to the higher possible rate of production, a very important effect upon economy of production. There are two principal reducing agents in the blast-furnace process, carbonic oxide and solid carbon, and it is generally accepted that reduction of iron oxide by carbonic oxide, in the upper zones, is a much more economical reaction than the reduction of iron oxide by solid carbon in the lower zones. It is, therefore, highly desirable that the whole or the greatest possible portion of the iron oxide should be reduced by carbonic oxide gas, and that this reduction should be completed before any lumps of iron oxide have reached the zone where conditions permit, in excess, the uneconomical reaction between them and solid carbon. It is obvious that the surest way of attaining this is to so increase the possible rate of reduction of the ore by increasing its surface area, as described above, that the maximum reduction may be effected by the carbonic oxide gas in the upper zones of the furnace. If this precaution of increasing the surface area by breaking the lumps of ore before charging into the furnace is neglected, the larger unbroken lumps will escape thorough reduction by carbonic oxide gas with consequent waste of fuel, particularly if any attempt be made to increase materially the rate of production by rapid driving. To obtain a high rate of production, with economy and quality, it is therefore necessary to prepare the ores in the manner described.

The degree to which it is commercially practicable to crush an ore depends upon its density. Experience has indicated that all ores should be crushed to sizes not exceeding such as will pass through a 3-inch or 4-inch ring, although ores of great density may be advantageously crushed to even smaller sizes. The standard of 3 or 4 inches, while seemingly rather small for ores of a high degree of reducibility—the so-called " soft " ores—is not determined wholly from the standpoint of degree of reducibility, but also by its bearing upon distribution.

The question of the distribution of ore in a blast-furnace is of the highest importance in its bearing upon regularity of operation, this in turn affecting most vitally the economy, quality, and output.

This question has been referred to above in a general way in connection with uniformity of action in the furnace, but important as that is as regards all the materials, solid and gaseous, entering into the blast-furnace operation, the distribution of the ore is the most important consideration in regard to the solid materials.

In the consideration of this question it is necessary to keep in mind the great essential—*equality of action throughout the whole of every cross section of the furnace interior.* Except for the fact that the operations are taking place in a vertical shaft of circular cross section, this result would be obtained, theoretically, only with materials of exact uniformity in size and density, but the fact just mentioned introduces a feature which interferes with this theoretical requirement. It is a well-known fact that the gases have a natural tendency to ascend next to the walls and would do so to the neglect of the interior if the furnace were filled with materials of exact uniformity in size and density. It is necessary, therefore, in order to secure approximate equality of action, to have a somewhat greater resistance to the passage of the gases in the materials nearest the walls than in the interior. It is to this condition that the ordinary bell and hopper charging apparatus owes its satisfactory use, discharging the materials as it does in such a way that a greater proportion of the smaller particles remains next to the walls, thus providing the somewhat greater resistance to the ascending gases required there. In order that this distribution by bell and hopper charging may give the desired result, the relation of the diameter of the bell to the diameter of the furnace throat at the stock line is of material importance, as likewise that the falling materials shall first strike the materials in the furnace, when nearly full, at about 18 inches from the walls. The former relation is usually a bell diameter 4 to 5 feet less than the throat diameter at the stock line. The bell angle is usually 40° to 45°, and in some cases 50°.

This method of charging results in the surface of the material in the furnace assuming the shape of an inverted cone with its base about 18 inches from the walls, from which point they slope away slightly to the surface of the walls. The smallest particles lie on the base of the cone, and between it and the walls, together with a portion of the smaller lumps and rubble. The inner slope from the base to the apex of the cone consists of pieces of gradually increasing size with practically only the largest lumps at and near the apex. This description does not, of course, apply to an ore mixture consisting of all fines, or of lumps of uniform size, conditions which very seldom exist in blast-furnace practice, but it does apply to the usual run of ores which consist of a mixture of fines, rubble, and lumps.

It is obvious that the greater the difference between the largest and the smallest pieces, or, in other words, the larger the lumps the greater the sorting action above described, and conversely, the smaller the maximum size of the lumps the less the degree of segregation. It is, therefore, further obvious that to avoid excessive segregation, the preparation of the ore by crushing the lumps to smaller, say rubble, size is necessary. The crushing of the lumps prevents excessive segregation in two ways, first, being smaller, they have less tendency to roll down the sides of the inverted cone to the apex, and, secondly, the broken pieces have usually sharp and jagged edges, and have, therefore, a greater tendency to lodge nearer where they fall, and the movement of the materials to the centre is more likely to be *en masse*, carrying a certain amount of smalls with it. It is thus that preparation by crushing materially improves distribution by preventing excessive segregation, which is a condition directly inimical to the application of modern blast-furnace practice.

In the distribution existing when the usual run of ores and limestone are charged " as received," there is, as described above, a core, or column in the centre of the furnace consisting almost entirely of the largest lumps, the area of the cross section of this core varying with the size and proportion of lumps to rubble and fines. Between this core and the walls there is an annular ring consisting of a mixture of rubble and smalls, in which the proportion of rubble to smalls gradually decreases until, next to the walls, there are practically only smalls and fines. As previously pointed out, an essential to regular and economical descent of the materials is perfect uniformity of action of the ascending gases upon the whole of every cross-section of the material in the furnace, and while this is an ideal condition which may be impossible of full attainment in actual practice, the nearest possible approach to it is of the greatest importance. There can be very little approach to such a condition if the ascending gases are forced, under pressure, through a mass of materials distributed as just described. Very little, if any, of the gases will find contact with the closely packed fine materials close to the walls, and the greater proportion will pass up through the more open structure in the centre, the core of large lumps, and a proportion only through the annular ring of rubble and smalls. The result of this unequal distribution of the ascending gases is the faster descent of the largest lumps in the centre, and a gradually slower descent of the outlying materials. Such a descending movement of the materials of the various sizes is exactly contrary to what is most desirable. Those which descend most rapidly, owing to their slower rate of reducibility should descend most slowly, and those which descend most slowly, owing to their high rate of reducibility should descend most rapidly. Maximum economy and output are impossible under such conditions, for, apart from the question of irregularity of movement which almost always results from them (see below), it is necessary to provide an excess of fuel to insure the complete reduction of the more rapidly descending lumps before they enter the melting zone (see above, under Reducibility), and the rate of driving is limited by their slower rate of reducibility. Any attempt at really fast driving under these conditions so reduces the ratio of ore to fuel which can be carried that not only is the output not increased, but the fuel consumption is very greatly increased, with the added danger of the production of low grade iron through unreduced ore entering the furnace hearth from over driving, or irregular descent of the materials.

Under the conditions existing in a furnace charged in the manner under consideration, there is always a strong tendency towards irregularity of movement, or none at all, in the material nearest the walls, with a gradual building up on the walls. This building up continues until portions either become permanently stationary, forming scaffolds, or masses break away and are precipitated towards the centre and into the actively descending materials and rapidly ascending gases, constituting the well-known slip. This procedure is more or less frequent and more or less severe, from the small slip, causing temporary production of off grade iron, to the heavy slip or explosion, which either blows off the furnace top, or fills the tuyeres with slag, chills the hearth, "gobbs up" the furnace and puts it out of commission for days, an evil too well known among those who may be interested in this paper to require any emphasis; but to whatever degree it occurs it very seriously interferes with the regularity which is essential to the best results. The disadvantages from the accumulated effects of these conditions are only avoided, and even then not always satisfactorily, by periodical partial clearance of the furnace walls by the use, temporarily, of considerably reduced burdens, or, which is the same thing, by charging extra fuel, at the expense of both economy and output. These evils can only be avoided by the proper preparation of lumpy ores by crushing.

Fine Ores.—The disturbing effects upon blast-furnace operations of the use of any considerable proportion of very fine ores—exaggerating the conditions described under Distribution—are too well known to require special emphasis. Although in modern practice furnace design and method of operation have considerably reduced these effects, such ores are still sufficiently objectionable in this respect to make advisable some treatment to change their character as fines. In this case the process of preparation is the reverse of that for lumpy ores, that is, instead of reducing, it is desirable to increase their size, in order to remove their clogging effect in the furnace, and to prevent their being carried out in excessive quantities, by the escaping gases, into the gas flues.

Various processes have been introduced for this purpose, such as briquetting, nodulising, and sintering, each of which yields a satisfactory product for use in the blast-furnace. Sintering is the more recent process, and has grown very rapidly in favour, owing to its lower production costs, and the large range of materials which may be treated by it, including blast-furnace flue-dust, the recovery of which alone in some cases warrants the installation of the process, particularly as, in addition to the iron ore recovered, the dust usually carries such an excess of fuel over what is required for its own treatment that a considerable proportion of other fine ore, without fuel, may be mixed and sintered with it. By these processes, and particularly sintering, many ores which, in their natural state, are unsuitable for use in the blast-furnace, either owing to their mechanical condition, or high sulphur content, or both, may be rendered suitable.

The Flux (Limestone or Dolomite).—Of the solid materials, the flux, being easily acted upon by the heat and chemical reactions, and usually forming a small proportion of the mixture, is of less importance in connection with the question of preparation of materials. It is of sufficient importance, however, to receive consideration, as its mechanical condition has a definite bearing both upon distribution and rapidity of action in their bearing on economy. Although the effect is less in degree, it is the same in principle as in the case of the ore, and for similar reasons the flux should be broken to as nearly as practicable uniform size. In practice it has been found sufficient to break it to sizes not exceeding 4 inches or 6 inches, or such as would pass through a 4-inch or 6-inch ring, although there is no disadvantage in breaking it to even smaller sizes. The author has had personal experience with large blast-furnaces using oyster shells alone as flux over a considerable period with perfectly satisfactory results, except that there was added to the waste gases a further objectionable feature to their usual asphyxiating qualities, their bad odour.

Blast.—The only remaining " raw material " essentially used in blast-furnace operation is the air which supplies the oxygen necessary for the combustion of the fuel.

There is little to be said with regard to the blast under the heading of Preparation of Materials, that is, in its bearing upon modern blast-furnace practice as distinguished from practice which is not " modern," except that the usual custom in the latter is to take the air as we find it, although not always in all its purity. Too little attention is usually paid to this point. Natural air in its purest state has its detrimental constituents, but as a rule little attempt is made to draw the supply for the blowing-engines even as pure as it occurs. The proximity of boilers and free exhaust auxiliary machinery, and various sources of evaporation, too often charge the air near blast-engine houses with quantities of moisture much in excess of that in natural air " in its purest state." In modern practice practically all exhaust steam is condensed, and a large proportion of the auxiliary machinery is electrically driven. There is, therefore, little, if any, opportunity for extraneous moisture to enter the blast-engines with natural air. This is a feature of considerable importance, and has an appreciable bearing upon the economy of modern practice.

Although in view of its lack of more general adoption it has no direct bearing upon the subject of this paper, there is a treatment to which natural air may be subjected for its improvement for blast-furnace purposes, which comes logically under the heading of Preparation of Materials. As a strong advocate of this treatment the author hopes that a discussion of it at this point will not be considered out of place. This is the question of dry blast, or, to be more exact, the treatment of natural air for reducing its hygroscopic moisture to a uniform and low content—a treatment practically demonstrated by James Gayley in 1904.

There has been a great deal of discussion, and even contention (mainly theoretical), as to the merits of this process. At the time of its introduction a great stir was caused in iron-producing centres, and during the following years a considerable number of plants were installed for its use in the United States more particularly, and in Europe. Some of these installations are still used continuously, and some are used intermittently in the United States, that is, they are used in the summer months when the moisture content of the air is high, and discontinued in the winter months when the moisture is naturally low. In other cases their use has been entirely discontinued.

There is, however, practically unanimous agreement amongst those who have used " dry blast " that its use does improve blast-furnace results, although opinions differ as to the degree of the economy. The author has had an opportunity during the past eighteen months of discussing this matter with representative American blast-furnace operators, particularly as to the reasons why the process has not been more generally adopted and its use continued more generally where plants have been installed. The explanation given is that the benefits obtainable from " dry blast " have been superseded by the great advance in blast-furnace results brought about in recent years by improvements in furnace design, and the altered practice following those improvements. In other words, it has been possible to obtain, in other ways, advantages equal to those derivable from " dry blast " under the older practice. It may be a very bold thing for the author to say in the face of these opinions, but he believes that attitude to be a mistaken one, and that if every advantage which can be derived from " dry blast " is provided for, further improved results are obtainable in addition to those already obtained by the means above referred to.

The author has had considerable experience with " dry blast," having used it continuously on two large furnaces during the past thirteen years with such satisfactory results that he would have considered its abandonment a very serious step in the wrong direction. It is not his intention to enter here into a discussion upon the advantages of " dry blast " in detail or in general, but there is one very important feature in connection with its use which seems to have been missed by those who have used and abandoned it, either partially or wholly, a feature which, in all probability, explains the attitude adopted towards it in the United States in conjunction with later American practice, and possibly elsewhere. This is the important factor of blast temperature. It is the author's experience, and he believes it is also general experience (although there may be isolated cases to the contrary), that with natural air there is an upper limit to the temperature of the blast which can be used with satisfactory and smooth working for any particular furnace. Any considerable increase beyond this limit causes "stickiness," "hanging," and irregular movement of the materials in the furnace. In his discussions with American blast-furnacemen he was told that this was the case even with furnaces of the latest design, and a particular case was cited at one of the most modern plants in America, where very high temperatures of blast were tried with results as above mentioned. The blast temperatures generally used range from 1150° F. to 1250° F., while with clean gas and modern stove design (and sufficient stove capacity), temperatures as high as 1500° F. to 1600° F. are obtainable.

The economical advantage which could be derived were it possible to make satisfactory use of this additional heat in the blast, need hardly be emphasised, and any practicable means which would render this possible would confer a very important boon upon the iron-producing industry. The author's experience is that such a means is available in "dry blast," and that it is this further advantage of dry blast added to those which are already conceded it, which would, if taken advantage of, settle the doubts of those who are still undecided, and convert those who have already condemned it. It may be said that he was in a fortunate position to have available such high temperatures (he has used temperatures as high as 1600° F., normally from 1450° to 1550° F., temperatures under 1400° F. being considered too low), but what was available to him is obtainable by others, and he would emphasise the fact that without dry blast, although available, he could not have used them.

II. Furnace Design.

In the sense in which this heading bears upon the purpose of this paper it refers not to the structural detail of the furnace as a whole, but to that portion only in which the metallurgical operations take place; that is, the furnace proper, the interior space, the design of which is technically known as the "lines of the furnace."

The terms usually used to describe the lines of a blast-furnace divide it into a number of sections, namely, the hearth or crucible, which is cylindrical; the bosh, an inverted truncated cone; the shaft, an upright truncated cone; and the throat—in modern furnaces usually cylindrical—extending from the top of the shaft to the top of the furnace.

The principal dimensions of these sections consist of heights, diameters, the acute angle of the bosh wall to the horizontal, and the batter of the shaft wall to the vertical. Each of these dimensions has a very important bearing upon all the others, and their relation to each other is of the first importance as a factor in modern blast-furnace practice; for although they may vary somewhat in their relation, the variations are limited to conform to certain principles, the height of the furnace and hearth diameter being the dimensions which control all the others.

Under this heading—Furnace Design—the author proposes to outline and discuss these principles, and to enunciate as a general law the principle that *the output capacity of a blast-furnace (with any particular set of raw materials) is in proportion to the effective bosh area.* The nucleus of this law is the word *effective*, for as will be later shown the maximum effective bosh area is dependent upon the various factors which constitute the principles of modern blast-furnace practice.

Modern development in blast-furnace design has established the following essentials. A shaft batter of 1 in 13·5 to 15, the low bosh, the large hearth diameter, and the steep bosh angle—all of which are, of course, comparative terms in their relation to similar features in the older designs.

Fig. 1 shows two furnaces, "A" and "B" of pre-modern lines (extreme cases have been chosen in order to emphasise the principles under discussion), and Fig. 2 two furnaces, " C " and " D " of modern lines (the tendency is further to increase the hearth diameter, and a furnace is now in successful operation with a hearth diameter of 20 feet 9 inches, but in this direction it is sufficient for the present purpose to avoid the extremes).

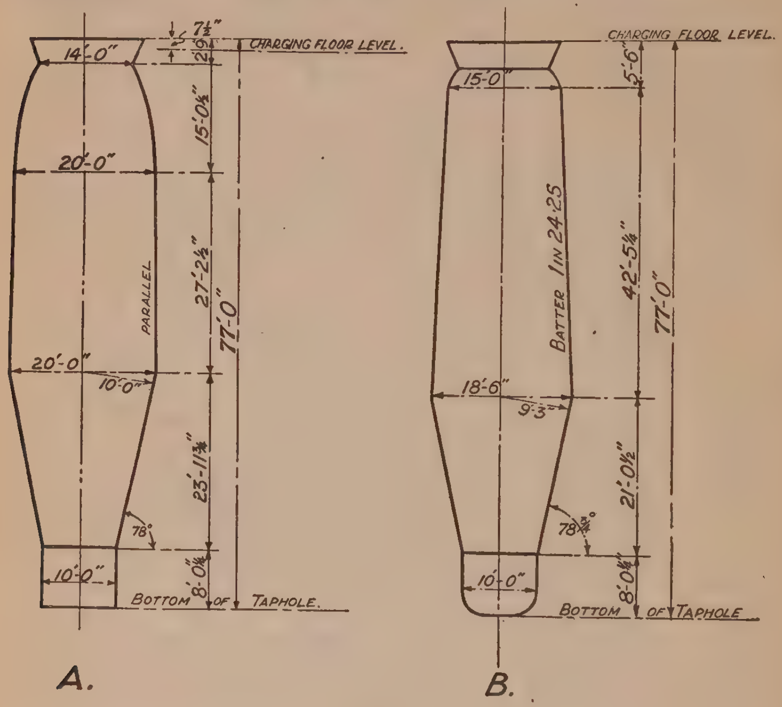
7½"
CHARGING FLOOR LEVEL.
14'-0"
2'9"
15'-0¼"
20'-0"
PARALLEL
27'-2½"
77'-0"
20'-0"
10'-0"
23'-11¾"
78°
10'-0"
8'-0¼"
BOTTOM OF TAPHOLE.
A.
CHARGING FLOOR LEVEL.
15'-0"
5'-6"
BATTER 1 IN 24.25
42'-5¼"
77'-0"
18'-6"
9'-3"
21'-0½"
78¾°
10'-0"
8'-0¼"
BOTTOM OF TAPHOLE
B.

FIG. 1.

Throat and Stack.—The upper section of the furnace or throat is, as above mentioned, usually cylindrical in shape and extends to from 20 feet to 25 feet below the furnace top or 12 feet to 17 feet below the stock line, the highest point to which the furnace may be filled. The adoption of the cylindrical throat is primarily in order to obtain the desired batter to the shaft walls, although it also has a bearing upon regularity of distribution by presenting to the charged materials an area of the same dimensions for the varying positions of the materials in the throat due to their constant movement. The latter point, however, is not of great importance in the modern furnace plant as the charging appliances are usually, or should be, of ample capacity to keep the furnace fully charged at the highest rate of driving.

Within the distance to which the cylindrical throat extends the condition of the materials is such that there is no tendency for them to adhere to the walls or to hang through jamming, or arching, as they are in a " dry " condition, both as to moisture and pastiness, and their expansion through increase in temperature is not yet sufficient to require increased space for their accommodation so as to avoid the danger of restricting free movement. Below this point, however, temperature increase becomes much more rapid and reactions much more intense. In this alteration in condition and temperature, which is progressive as the materials

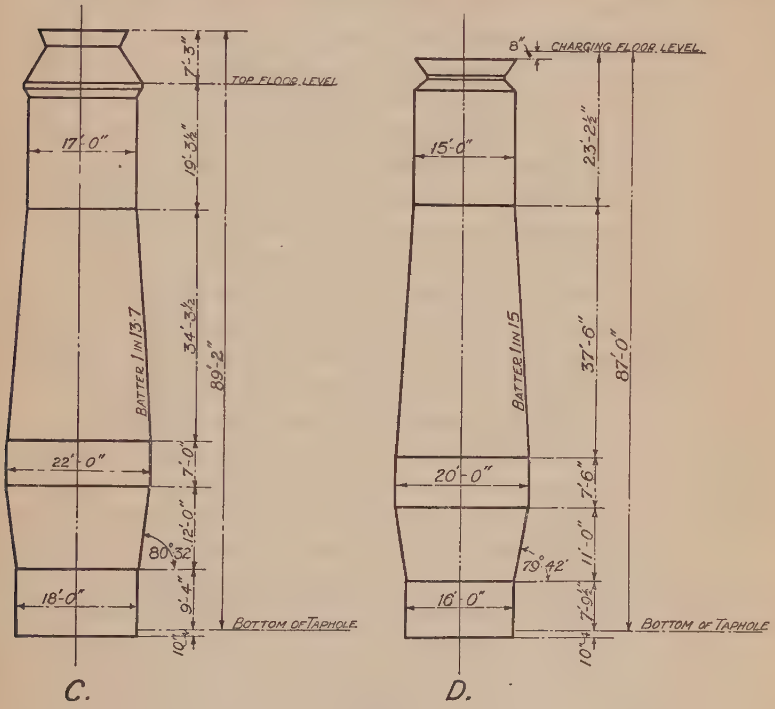
7'-3"
TOP FLOOR LEVEL
17'-0"
19'-3½"
34'-3½
89'-2"
BATTER 1 IN 13·7
22'-0"
7'-0"
12'-0"
80°32'
18'-0"
9'-4"
BOTTOM OF TAPHOLE
10"
C.
8"
CHARGING FLOOR LEVEL.
15'-0"
23'-2½"
37'-6"
87'-0"
BATTER 1 IN 15
20'-0"
7'-6"
11'-0"
79°42'
16'-0"
7'-9½"
BOTTOM OF TAPHOLE
10"
D.

FIG. 2.

descend, more space accommodation is required for free movement, more particularly because to expansion is added the semi-pasty and pasty condition, and the increased density of the mass through the increasing load bearing down upon it from the increasing weight of superimposed materials. It is also probable that the question of carbon deposition enters into the necessity for greater space accommodation as the materials descend into the hotter and more active regions of the furnace. Hence the necessity for the expanding batter to the shaft walls. It would also seem obvious that the more rapid the descent of the materials into and through these zones (faster driving), the greater must be the increase in space accommodation. In the older furnace designs, with slower driving, shaft batters as low as 1 in 26, and possibly less, were in use. In modern practice it has been found necessary to increase this batter to 1 in 14, or thereabouts. The principles involved in this feature of modern blast-furnace design are of the greatest importance, and probably explain, in part at least, why many furnace managers have failed in their attempts to apply fast driving to furnaces with lower shaft batter.

To revert for a moment to throat diameter, there are in this feature several opposing conditions to consider. The lower the velocity of the gases as they leave the furnace top, the lower the loss from flue dust carried over with them. The largest possible throat diameter is, therefore, desirable for this reason. On the other hand, the extent to which this feature may be provided for is limited by the question of distribution, both of the materials charged into the top and the ascending gases, as regards the most uniform action of the latter over the whole cross-section of the former. The throat diameter is also limited by the required shaft batter, and the bosh diameter and height. Sacrifices must, therefore, be made in one direction or the other, and as the question of losses by flue dust is largely affected by regularity of stock movement, features tending to the latter should have first consideration. Throat diameters are, therefore, restricted in modern furnaces of 85 to 95 feet in height to from 15 to 17 feet, the controlling factors being the other dimensions such as hearth diameter, bosh diameter, and height.

The Low Bosh.—The low bosh was the direct outcome of attempts to increase blast-furnace outputs by increasing the volume of blast blown per minute. These attempts with the old high bosh furnaces resulted in seriously increased furnace irregularities, the reason for which became apparent from the study of the altered conditions brought about in the furnace through the more rapid driving, and the troubles experienced. With the much more rapidly descending materials it was found necessary that the contracting part of the furnace, that is, the top of the bosh, should begin below the upper limit of the zone of fusion in order to prevent the pasty materials just above the zone of fusion entering the contracting area, where they would be subjected to a squeezing action as a result of the resistance of the bosh walls, and the weight of the superimposed materials, with the consequent tendency to pack and cause hanging and the formation of scaffolds on the upper bosh walls.

The continued lowering of the top of the bosh followed therefore the continued attempts at faster rates of driving for larger outputs, until in modern practice a bosh height for 85 to 95 feet furnaces, of 10 to 12 feet above the top of the crucible, has been adopted as compared with as much as 30 feet in the old design. Whilst it is true that no one would build a furnace with a 30-feet high bosh to-day, there are furnaces in operation of recent design with boshes 16 to 18 feet or even higher. Any attempt rapidly to drive such furnaces is sure to result in increased irregularity and consequent failure. The basis of this principle—the low bosh—is, therefore, that the furnace must be so designed, as regards bosh height, that the expanding portion of the furnace, that is, the shaft, shall continue to a point slightly below the beginning of the melting zone, so that no pasty materials shall enter the contracting portion at the top of the bosh. In actual practice many, in fact most, modern furnaces are designed with a cylindrical section from 5 to 8 feet in height between the lower limit of the expanding shaft and the upper limit of the contracting bosh. This section has no justification from the standpoint of any principles involved in its adoption, except that it fills up with brickwork the angular space at the junction of the bosh and shaft, which to a degree may be considered "dead space," and renders less abrupt the transition from the expanding shaft to the contracting bosh, but is rather the result of necessity in order to obtain the desired relation between other features such as shaft batter, throat diameter, and bosh diameter and height.

The bosh diameters, for what may be called full-sized blast-furnaces, that is from 85 to 95 feet high, are usually from 20 to 23 feet with a bosh angle of about 80°, while in pre-modern designs this angle was anything from 68° or less to 74°. The steeper angle is the result of the progressive increase in hearth diameters, and, as the author will endeavour to show further on, both these features, the steep bosh angle and the large hearth, are concomitant, and their evolution the result of efforts to overcome irregularities through the failure of earlier designs (with the flatter bosh and smaller hearth diameter) to bring into operation the maximum effective bosh area, which is, of course, the full bosh area.

The Hearth or Crucible.—In the modern full-sized furnaces hearth diameters are normally from 16 to 18 feet, although, as has already been mentioned, in one instance this dimension has reached 20 feet 9 inches. At present, however, the latter may be taken as an extreme, and it remains to be seen whether hearths of this size are likely to be generally adopted. In the process of evolutionary experiment it is often necessary to overreach the maximum in order to ascertain what it really is.

The hearth diameter of a blast-furnace would seem, at first sight, to be the determining factor for its output capacity, and, in the sense that it is the starting point in the design, and, with the bosh angle and bosh height now generally adopted in modern design, practically determines the bosh diameter, it is so, but in the sense that the hearth diameter, together with the low bosh and steep bosh angle, are merely means for making effective the maximum bosh area it is not really the determining factor, which is the bosh diameter. The hearth, or more properly the crucible, is the receptacle for receiving and storing from cast to cast the molten materials, while the bosh area is the active area in which the molten materials are produced as such, and the proportion of that area which is in active operation is the determining factor as to the quantity of molten materials available for collection in the crucible.

In all previous references to the various dimensions of the modern blast-furnace, and the principles which have led to their adoption, it is, of course, assumed that in the operation of the furnace the volume of blast is in keeping with the size of the furnace, and is such as will provide the operating conditions upon which those principles are based. In modern practice the volume of blast blown is normally from 40,000 to 50,000 cubic feet of free air per minute delivered from engines capable of delivering these volumes against pressures, or rather resistances, up to 25 or 30 lbs. per square inch, to provide ample reserve power for conditions causing abnormally high pressures. Normal working pressures are usually between 15 and 20 lbs.

Effective Bosh Area.—This term, used several times in the foregoing, is, the author believes, a new one in blast-furnace nomenclature, but it is one which has a meaning of the first importance in blast-furnace operations.

On p. 23 was enunciated as a general law that " the output capacity of a blast-furnace, with any particular set of raw materials, is in proportion to its *effective* bosh area."

Before discussing this proposition it is necessary to define :

1. What is the " effective bosh area " ?—and to consider :
2. What are the factors which control or determine the effective bosh area ?
3. What bearing have these factors (through their determination of the effective bosh area) upon the output capacity of the furnace ?

1. The effective bosh area is that portion of the full horizontal bosh area at its maximum diameter which is in normal activity under the conditions of operation of the furnace.

2. The factors which control or determine the effective bosh area are those which are under discussion in this paper, namely, the condition of the materials charged, the furnace lines, and the volume of blast blown per minute in relation to the size of the furnace.

3. The bearing these factors have upon the output capacity of the furnace is that they determine the area of activity in the melting zone.

The whole trend of evolution in blast-furnace practice has been in attempts to devise means of increasing output capacity consistent, of course, with quality and economy, and the degree to which these attempts have been successful in modern practice has been due to the influence of the factors in that practice, as described in this paper, in increasing the ratio of effective bosh area to the maximum or designed bosh area of the furnace, or to put it in simple terms *to keeping the walls clean*. It is, therefore, conversely true that the effective bosh area of blast-furnaces, where the factors upon which modern practice is based have not been adopted, or which are not operated in conformity with its principles, is less than the maximum or designed bosh area.

As has been described under Preparation of Materials, the direct tendency of lack of such preparation is towards restriction of active area in the furnace. Under furnace design the tendency of the high bosh and the low stack batter is shown to be towards restriction of active area in the furnace. Equally the tendency of the small hearth and flat bosh angle is towards restriction of effective bosh area, owing to the removal of the area at and adjacent to the top of the bosh near the walls too far horizontally from the upward moving gases, with the consequent tendency for accumulation of torpid or stationary materials in that area.

As previously described, for a furnace of given size, insufficient blast volume to ensure equal activity throughout the whole cross-section at every altitude tends to the production of inactive areas owing to the impossibility of providing perfect uniformity of materials. The greater this lack of uniformity, the greater this tendency. The under blowing of a blast-furnace is one of the most fruitful causes of reduction of effective bosh area, with outputs far below maximum output capacity.

The tendency of a blast-furnace is to adjust its active areas to the volume of blast supplied to it. This tendency is in strong evidence where furnaces which have been blown for a considerable period with comparatively small blast volume, have been suddenly and too quickly supplied with a considerably increased volume. Operators who have made this experiment will doubtless recall the difficulties they have experienced through irregular working. The author knows of cases where, although the furnace size was quite suitable to the increased blast volume, the attempt has been abandoned through the conclusion that conditions were not suitable to faster driving, whereas a little persistence would probably have overcome the difficulties met with by the walls gradually clearing, and the furnace thus adjusting itself to the larger blast volume.

It is, of course, true that many blast-furnaces in operation to-day are not adaptable to modern practice in its fullest sense. One or more of the necessary factors are lacking, and, as the author has attempted to show, each of these factors is so dependent upon the others that they must all be present for its full application. Among them, however, there is one, preparation of materials, which, if adopted alone, would provide conditions which would render possible the partial application of others with decided improvement in results, and tend to remove many of the difficulties now experienced.

III. Auxiliary Equipment.

Under this heading it is not intended to enter into, nor does the purpose of this paper call for, a detailed discussion of the many units comprising the auxiliary equipment of a modern blast-furnace. There are, of course, certain units which are essential to the operation of any blast-furnace. Where, for the purpose of emphasising the requirements of modern blast-furnace practice, it is necessary to discuss the modern features of these units they will be specifically referred to. There are also certain units which, while not essential to blast-furnace operation in general, are essentials, from the standpoint of economical operation, to modern practice. These will be discussed in more detail, but only so far as the principles involved in their adoption are concerned.

The auxiliary equipment, or plant required for the operation of a blast-furnace, may be divided into four sections :

1. The Power Plant.
2. The Blast Heating Plant.
3. The Raw Material Supply Plant.
4. The Output Disposal Plant.

Equipment falling under one or other of these sections is essential to the operation of every blast-furnace (excepting, of course, a cold-blast furnace which need not be considered here). In modern practice, however, there are certain features in the details of the plant required, bearing upon the method and economy of operation, which are essential to the full adoption of that practice.

1. The term *Power Plant,* which is used here in its most comprehensive sense, covers all apparatus for producing and utilising the power required for sustaining the blast-furnace operations. The principal among these are the boiler plant, the blowing-engine plant, the electric generating plant, the water-pumping plant, and, in some cases, the hydraulic power and compressed air plant (and it might be added the dry-blast plant). With regard to most of these items, it need only be said that they should be of the most modern, simple, and economical type, with ample reserve of power and capacity, in order to minimise those costly furnace stoppages which are otherwise likely to occur through mechanical failures, or interference with normal operation through lack of efficiency. In other respects they do not, with the exception of the blowing-engines, bear directly upon the principles of modern blast-furnace practice. In regard to blowing-engine capacity, and —in one particular feature—to turbo blowers, there is a point which it is important to emphasise. As previously stated, the volume of air required for the normal operation of a full-sized modern blast-furnace is from 40,000 to 50,000 cubic feet of air per minute. It is important that this air should be delivered in as continuous a flow—that is as free from pulsations—as possible.

With reciprocating engines, the speed and number of blowing cylinders should be as great as possible consistent with engine safety and efficiency, and the range of volume delivered, with a fair degree of economy, as wide as possible. The engines should also be designed to deliver their maximum volume against pressures up to 25 to 30 lbs. per square inch with steam pressure or gas of quality at least 20 per cent. below the normal, in order to provide for those abnormal conditions to which every blast-furnace is liable. As regularity in air volume delivery is an essential of modern blast-furnace practice, every blowing-engine should be equipped with an efficient governing device.

As above mentioned, the centrifugal or turbo blower is widely used, and is rapidly growing in favour for blast-furnace work. Well-designed blowers of this type have a number of advantages over the reciprocating type. They are simpler in design. Per unit of capacity they are lighter in weight, require less floor space, less massive foundations, and are lower in first cost. They have fewer moving parts, have no losses through reversal of motion, are lower in cost of maintenance and repairs, require less attention in operation, and are much easier and less costly to lubricate. They have the advantage of giving a continuous flow of blast delivery, being entirely free from the pulsations in delivery, within their rated capacity, characteristic of the reciprocating type. There is, however, one feature in the turbo blower, as compared with the reciprocating blower, which must be specially provided for to ensure its suitability for modern blast-furnace practice. As above stated, regularity or constancy of the volume of free air per minute, required by the furnace operator for the time being, is an essential of that practice. This volume must not materially vary or be affected by the more or less varying resistance, commonly called pressure, on the delivery side of the blower, due to the varying furnace conditions. In reciprocating blowers this requirement offers no difficulty, as regularity of the volume delivered is assured by regularity in engine revolutions, whatever the resistance, within the limits of the capacity of the blower. In the turbo blower, however, the volume delivered varies both with the engine revolutions and the resistance on the delivery side. The turbo blower, therefore, requires for its satisfactory application to modern blast-furnace practice a special type of governing or controlling device in order to assure the delivery of a constant volume of blast per minute against the varying resistance offered by the varying furnace conditions, that is, a volume controller. For many years this feature in the turbo blower was a serious drawback, notwithstanding its many other advantages, to its adoption for blast-furnaces. Its general adoption and growing use in recent years is directly due to this difficulty having been successfully solved through the design and application of an efficient volume regulator.

2. *The Blast Heating Plant* consists essentially of the hot-blast stoves and their connections, for receiving cold-blast from the blowers and waste gases from the furnace, and for delivering hot-blast to the furnace and consumed gases to the atmosphere. Under this heading should be included another installation which, while not essential to blast-furnace operation in general, is from

the standpoint of economy an essential part of modern blast-furnace equipment. This is the gas-cleaning plant, or rather, a rough gas-cleaning plant as distinct from the plant required for the high degree of gas-cleaning necessary for use in gas-engines.

The advantages and economies obtainable by the use of clean gas as compared with uncleaned gas are many and of very considerable importance, and far outweigh the cost of installation, operation, and upkeep, &c.

Though this question has already been fully discussed by various writers, a number of these advantages, some of which also apply to the boiler plant, are enumerated as follows:

(1) A much higher thermal efficiency of the gas is obtained through more perfect combustion, by better control of air and gas mixture, and the elimination of fume and other heat absorbing solid matter, with the consequent increase in the heat units available for absorption by the stove checker bricks and boiler flues

(2) The saving of the labour constantly required for cleaning stoves and boiler flues.

(3) The saving of labour and materials required for repairs to stoves necessitated by the fluxing effect of the solid matter in uncleaned gas on the brickwork.

(4) The much longer life of stove linings through the absence of these destructive effects of uncleaned gas.

(5) The much greater time service per stove—and per boiler—through the elimination of lost time for cleaning and repairs.

(6) The much greater possible heating surface per unit of stove volume through the use of smaller checker openings, and the higher efficiency thus obtainable.

(7) The greater regularity in blast temperatures obtainable through the maintenance of a higher average stove efficiency.

(8) The hot-blast being practically free from abrasive dust there is an absence of its cutting (sand-blast) action upon the linings of the hot-blast connections and of the iron and steel fittings where blast leaks are liable to occur.

The very large volumes of blast used in modern blast-furnace practice naturally necessitate stoves of much greater heating surface than is required in the older practice. The modern hot-blast stove is, therefore, constructed with a heating surface of 70,000 to 85,000 square feet; checker openings are from 3 inches to 4 inches in diameter or square, enclosed in a shell 20 to 22 feet in diameter and from 95 to 110 feet in height. There are usually four stoves per furnace, though in some cases seven stoves are provided for two furnaces, one being arranged so that it may be used on either furnace. This is open to the objection that the two furnaces may at times both need the extra stove to the probable disadvantage of one. Each furnace should have its own complete equipment when both are in operation. The stove shells and their fittings and connections must be of considerably greater strength than in the older constructions to withstand the higher pressures they are subject to, and the latter of ample area to accommodate freely the large volume of air and gas passing through them.

A small but important feature in modern blast-furnace equipment is the blast temperature regulating pipe, which consists of a connection between the cold- and hot-blast mains. The purpose of this connection is for admitting cold-blast direct into the hot-blast main to enable the regulation of the blast temperature, usually downward, when required. The cold-blast connection may be made at any convenient point in the cold-blast main, but the connection into the hot-blast main should be at the furthest possible point from the furnace to intercept the blast from the nearest stove, in order that the cold- and hot-blast may have as great as possible time thoroughly to mix, as otherwise there is danger of the cold- and hot-blast entering the bustle pipe, or circular main, from which the tuyere connections are fed, not thoroughly mixed, when some of the tuyeres will receive blast of higher temperature than others with consequent uneven working of the furnace.

3. *The Raw Material Supply Plant*—While unquestionably economy in the cost of handling the raw materials for supplying the furnace has grown to be a first consideration in the design of the plant under this heading, particularly in recent years of high labour costs, the original incentive to the adoption of mechanical

handling was rather one of necessity. The rapid increase in blast-furnace outputs necessitated such large quantities of materials that they could not be efficiently handled, if at all, by the older methods of manual labour. It was therefore necessary to install mechanical charging devices. Labour displacement rather than necessary labour saving was the primary incentive, though the latter was undoubtedly recognised as an important consideration.

A very important labour-saving feature is that the raw materials shall be delivered to the works, when by rail, in self-discharging hopper wagons of as large capacity as possible, with "one man" opening and shutting doors; when by sea direct from the ship, by means of large capacity grabs to a transfer travelling bridge, which delivers the material so received direct to the furnace bins, to the stockyard situated adjacent to the bins, and directly under the transfer bridge, or into railway wagons. The bins usually consist of a double row of slanting bottomed enclosures, constructed of steel or concrete, varying in number according to varieties of ores used, and running usually in a direction perpendicular to the length of the transfer bridge, the inclination of the bottom being towards the centre line between the two rows of bins and at an angle somewhat greater than the angle of repose of the materials. The bins are each of moderate capacity, but in total capacity usually sufficient to supply the furnace for from forty-eight to seventy-two hours only, as by means of the transfer bridge ample facilities are at hand to keep them filled from the stock piles if necessary. Each row of bins forms the support for a standard gauge railway track for conveying to and discharging into the various bins such materials as are received in railway wagons. A transfer car also runs on this track, or on a separate track supported by the bins, for distributing the materials delivered by the transfer bridge from the stock piles or direct from the ships. The railway wagons are elevated to the roads over the bins, either by an electric lift, or over an incline where there is sufficient room, the wagons descending to the ground level either over the same incline or a similar one at the other end or by means of a wagon drop.

Below and on the centre line between the double row of bins there runs an electric transfer car for conveying the materials from the bins to the hoist skip or bucket. The materials are discharged from the bins by gravity into a receptacle on the transfer car, through suitably controlled openings situated at the lower limit of the inclined bottoms of the bins. The transfer car also carries as an integral part of it a weighing machine, upon the beams of which rests the receptacle for receiving the materials from the bins, so that any predetermined weight of material may be discharged into the transfer car receptacle from any particular bin. The whole of the operations in connection with the transfer car are carried out by the driver of the car, whose position is such that he has under his control and observation the discharge of the materials from the bins, the weighing of the materials, and the driving of the car. The capacity of the transfer car is such that it can deliver in each trip a quantity equal to the maximum load of the hoisting skip or bucket.

Various means are in use for assuring that the materials are well distributed as they discharge into the transfer car receptacle. From this receptacle the materials are discharged through a suitably controlled door in the bottom into the hoist receptacle, or, as in some arrangements, the transfer car receptacle is hoisted direct from its seat on the car to the top of the furnace.

Several methods of hoisting the materials to the top of the furnaces are in use in modern blast-furnace equipment, which may be divided into two classes—the skip inclined hoist and the tub or bucket hoist, the latter consisting of either an inclined bucket hoist, or a vertical bucket hoist with a horizontal transfer bridge at the top. As usual where several methods are in use for doing the same thing, engineers and operators differ as to which provides the greatest number of desirable features for its purpose. As far as this paper is concerned, however, the purpose is the same in each method, and the author does not, therefore, propose to enter into a discussion of their relative merits.

That purpose is obviously to deliver the solid raw materials required in the production of pig iron to the top of the furnace, and to distribute them as uniformly as possible on and around the furnace charging bell. This is a feature of the greatest importance, as has been shown in the discussion of the question of distribution under the section on Preparation of Materials.

4. *The Output Disposal Plant.*—The principal output from a blast-furnace is, of course, pig or molten iron, the others being slag and gas.

With modern blast-furnace equipment the pig, or casting, bed has ceased to exist as an essential part of the furnace equipment, the whole of the output being run into ladle cars of varying capacity, from the simple open top type of 30 or more tons to the large enclosed type of 100 or more tons capacity, though in some cases even the use of hot metal ladle cars is eliminated, as will be described later in connection with the casting machine. When the molten metal is taken to the steelworks receiver or mixer there is an end of it as far as the blast-furnace is concerned, excepting when the quality is not satisfactory to the steelworks manager. When all or any portion of the output is required in the form of pigs, the molten metal is run into ladle cars for conveyance to a casting machine, which is usually located at some point away from the furnace, convenient to railway connections, or as in some more recent arrangements, the casting machine is located adjacent to the furnace, the molten metal being run direct into a receiver from which it is teemed into the casting machine feeding troughs, thus eliminating the necessity for hot metal ladle cars, except for such molten metal as is required for steel-making.

Though several types of pig-casting machines have been designed, the original or Uhling design, with various modifications and improvements for handling the molten and cold metal, is the type most usually installed at present. This machine consists of an endless chain of cast-iron moulds of about 100 lbs. capacity each, and of a shape to allow a free discharge of the cold metal. The moulds are key bolted to a flexible frame carried on small flanged wheels which run on an inclined way rising from the pouring end. The molten metal is poured from the ladles, which are tilted by a power device, into a shallow basin from which it runs through feeding troughs into the moulds as they rise slowly from their return journey and pass under the discharge end of the troughs. To prevent the molten metal burning or sticking to the moulds, they are coated with a solution of limewater, which is sprayed upon them as they return to the pouring end upside down, under the machine, the limewater being blown upward by air jets in the lime tank. Owing to the heat of the moulds they quickly dry in readiness for the molten metal before they reach the feeding troughs. At the upper end of the train of moulds as they turn over to begin their return journey, the metal, which by this time has solidified (the incline is designed of sufficient length for this purpose), freely falls from the moulds on to a shute from which it discharges either direct into steel-bodied wagons where it is water-sprayed for cooling, or on to an inclined travelling endless plate conveyor which passes with its burden of hot pigs through a water-filled tank of a length sufficient to cool the pigs below the ignition point of wood. At the upper end of the conveyor as it turns for the return journey the cold pigs slide off into a shute and are discharged into railway wagons.

Machines are built single strand or multiple strand according to the capacity required, each strand consisting of a single chain of moulds having a capacity of roughly 500 tons per twenty-four hours.

While the structural parts of these machines were formerly built entirely of steel they are now constructed of ferro-concrete, owing to its more lasting qualities and lower cost. In addition to the necessary facilities which it provides for casting the large outputs of the modern blast-furnace, the pig-casting machine, the successful and satisfactory operation of which has been thoroughly demonstrated through many years of use, has very much simplified the handling of molten pig iron by eliminating the many objectionable features of the older method of casting in sand beds, and breaking by hand or by hydraulic or electrical pig-breaking machines, besides effecting considerable economy of labour and saving in waste.

The disadvantages of sand-bed casting and the advantages of the machine method of handling molten pig iron may be enumerated as follows.

Disadvantages of the sand-casting method :

(1) Difficult and high-priced labour required.
(2) Large quantities of clean sand required.
(3) Imperfect results, core jumps, plated beds, irregular breaking, and irregularity in sizes of pigs and sows.
(4) Heavy waste in runner scrap.

(5) Slower melting of sand-covered pigs, and cost of melting the sand on the pigs, in the steel furnace.
(6) Deleterious effects of sand-covered iron in basic steel furnaces.

Advantages of the pig-casting machine method :

(1) Immediate removal of molten metal from the immediate vicinity of the blast-furnace. (This, of course, does not apply where the metal is run direct into a receiver adjacent to the furnace, as above described; but the author believes this arrangement has not yet been widely adopted, and is of opinion that, notwithstanding the slightly extra cost of ladle cars, it is better to remove the molten metal to a safer distance, in view of the disturbances which sometimes occur in the immediate vicinity of blast-furnaces through breakouts, explosions, &c.)
(2) Practically no manual labour required.
(3) Sand-free iron.
(4) Uniform size of pigs of iron, and no heavy sow pieces.
(5) Facilities for disposal of the output always in readiness.
(6) Great reduction in runner scrap produced when casting.
(7) Saving in labour charges.
(8) No core-jumps or plated beds (unsaleable iron requiring extra labour for breaking and handling).
(9) A difficult and very trying class of labour is dispensed with.
(10) Where week-end iron only is cast, the difficulty of finding special labour for these days only is eliminated.

A discussion of this heading would not be complete without reference to the slag and gas, both of which form part of the furnace output.

While there are no special methods of slag disposal which may properly be said to apply particularly to modern blast-furnace practice, it may not be amiss to refer to some of the methods in use at modern plants.

The most usual method is, of course, that which is now generally used at all, except the oldest, layouts (where the slag is still run into beds, allowed to cool, then broken by hand or drop ball, and shovelled into wagons), that is, by means of large capacity, self-discharging, mechanically operated slag ladle cars, in which the slag is conveyed to some point more or less distant to get it out of the way.

Where, however, recovery of the slag is desired for special commercial purposes, special methods are used, such as blowing steam through the molten slag for the production of slag wool; running the molten slag into tanks of water for granulating for cement making or other uses; running into special receptacles and cooled in layers for producing a solid product for concrete making, &c. As stated, these processes are for special purposes, and do not apply generally.

With regard to the gas there are a few points also which may be mentioned.

In view of the large volumes of gas produced in modern furnaces with large outputs, it is of great importance that ample areas shall be provided in the gas outtakes at the furnace top, not only to provide for the large volume of gas to be discharged through them, but also to reduce its velocity to a minimum, in order to lessen as much as possible the tendency for the smaller particles of solid materials to be mechanically carried out with the gas. For this purpose it is usual to provide four equally distant outlets of the largest size consistent with structural safety. These outlet connections are inclined as steeply as possible upward, and are carried well above the furnace top before the gas is admitted to the downward connections, in order that any larger materials, which may at times be projected from the furnace, may fall back into it and not enter the downtakes.

In some designs baffles are placed in the elbow of the uptakes in such a position that they will intercept these heavier pieces, thus avoiding the necessity for carrying the uptakes so high. A further reason for the multiple equidistant outlets is to prevent any tendency of the gases in the upper portion of the furnace to channel towards one side, as they tend to do in older furnaces with one outlet, thus reducing the active area in the upper reducing zone of the furnace.

IV. Method of Operation.

In the foregoing pages the author has endeavoured to define in some detail those factors which enter into, and make possible, modern blast-furnace practice. They are the elements out of the adoption of which that practice has developed. He has therefore designated them "The Bases of Modern Blast-Furnace Practice."

Certain operative features have necessarily been referred to in connection with the discussion of these factors; but so many of the details of operation, or management of a blast-furnace, are based on practical knowledge, acquired only by years of experience and common sense, that any detailed discussion of them is not possible in a paper of this nature.

It would not, however, be complete without some reference to an essential difference in the method of operation by which the improvements in results, made possible by the adoption of these factors, are obtained, and the method of operation still prevalent in many localities where modern practice has not been adopted. In modern practice the nearest possible approach to uniformity in all controllable factors is a first principle in order to obtain the nearest possible approach to uniformity of action within the furnace. Reference has already been made to the importance of this question of uniformity in various connections, *including uniformity or regularity of blast volume, irrespective of furnace pressure or resistance.* In the older practice just referred to as still prevalent in many localities, the volume of blast is varied with the furnace resistance, that is, the varying conditions within the furnace are permitted to cause lack of uniformity or irregularity in the volume of blast delivered to the furnace. This method being contrary to the principle of uniformity of all controllable factors is totally inapplicable to modern practice.

As the principle involved in the comparison of these two methods of operation were outlined in some detail in the author's evidence before the Iron and Steel Industries Committee, he will not state them here. Suffice it to say that blowing by constant volume irrespective of furnace resistance is the method of operation essentially employed in modern blast-furnace practice.

The actual volume of blast per minute, the number, size, and length of projection of the tuyeres inside the crucible walls, the weight of coke per round of charge, the rotation of coke, ore, and flux in the charge, the degree of bosh wall cooling, &c., are all operating conditions determinable, for any particular furnace and set of materials, within certain limits by experience only.

DISCUSSION.

Professor Henry Louis, Member of Council, said that he would not refer to the very many points upon which he was in complete agreement with Mr. Reese's excellent paper, but would open the discussion by a reference to two points on which he ventured to differ from that gentleman, one being a question of fact and the other one of opinion. He held that Mr. Reese was wrong in saying that dry blast was first introduced and demonstrated by Mr. James Gayley in the United States. He was under the impression that the first experiments with dry blast were carried out by the late Mr. Charles Cochrane at Middlesbrough some thirty or forty years ago. He dried his blast by passing it over quicklime, and he (Professor Louis) believed that he came to the conclusion that advantage was derived thereby, but not sufficient to compensate for the cost of that method of drying. He suspected that most users, even of the modern method of drying the blast, had come to a not dissimilar conclusion.

His other point was that he differed from the ideal put forward by Mr. Reese, namely "the attainment of the greatest possible quantity consistent with quality." That was a thoroughly American idea, but he doubted whether it were really sound; his own view was that what should be aimed at was the greatest possible *economy* consistent with quality; economy and quantity of output were by no means identical. Mr. Reese advocated the American principle, the blast-furnace with the huge output of, say 600 tons per day. If he (Professor Louis) had to produce 1800 tons of pig iron per day, he would prefer to put in six blast-furnaces making 300 tons each rather than three blast-furnaces making 600 tons each. He believed in splitting his risks; if one of the furnaces went out of blast Mr. Reese would lose one-third of his output and one-third of his gas, whilst he (Professor Louis) would lose only one-sixth of each. The greatest economy, at any rate in fuel consumption (which nowadays was of the utmost importance), appeared to be attained in furnaces of relatively moderate size. He admitted that six blast-furnaces would probably be a somewhat more expensive plant than the three furnaces advocated by Mr. Reese, but in the manufacture of pig iron the item of interest on and redemption of capital did not bear any very important ratio to the total cost of production, whereas economy in fuel was probably the most important factor. He held that the best possible furnace was the furnace that was the most economical in fuel.

Very fine ores required agglomerating, as Mr. Reese pointed out, and very lumpy ores required breaking smaller; there must therefore be a margin of size that required no preliminary treatment of one kind or the other, and it would be interesting if Mr. Reese would indicate what he held to be the limits of size within which no such treatment was required.

Mr. Guy Barrett (Wigan) said Mr. Reese referred to the necessity for removing the small coke. Those who had worked with unscreened and dirty coke in recent years well knew that the small in the coke was detrimental for more reasons than merely on account of its size. It was preaching to the converted to say to those who worked blast-furnaces that the coke should be screened. It was surprising to find how much ash the small sometimes contained. There was doubtless room for much improvement in the direction of improved coal washing, the expenditure in connection with which would generally be fully justified. There were strong arguments in favour of buying coke on its analysis, and such difficulties as might be involved could be overcome. With regard to the grading of ores, relatively few blast-furnacemen in Great Britain had had experience of deliberately reducing the size of the ore, though most of them had had experience of involuntary grading and its very detrimental effect on the working of the furnace. In connection with the conversion of magnetite ore, he was not quite sure whether Mr. Reese suggested it could be done in the lump state. He (Mr. Barrett) thought it would need crushing before it could be done successfully. Nor was he sure that he agreed with Mr. Reese's remarks in respect of limestone. Limestone should be graded to regular size in the same way as the ore and fuel.

On the question of dry blast he had a fairly open mind. The reasons given at different plants for its abandonment were very diverse, but broadly it might be concluded that it had not been a success financially. Mr. Reese mentioned 1400° F. as a regular blast temperature; he would like to ask if there had been any difficulties with the hot-blast valves. An investigation he had recently made in regard to the results obtained from furnaces in various parts of the country and working widely different ores had shown that those with the lower boshes and higher shaft batter had produced the best results. With regard to the bosh area he would mention that Mr. Clements, in a paper read before the Institute in 1920, had called attention to the distinction between "bosh area" and "effective bosh area." In that connection he thought that the long lives reported for the linings of certain furnaces with unusually large boshes were not due to the direct effect of the large bosh but to the fact that it gave rise to a large ineffective area filled with a carbonaceous deposit which effectively protected the brickwork from the effects of the gases and descending material.

On the question of the hearth, he agreed with Mr. Reese that probably the economical limit had been passed. He had not worked a large hearth, but conversations he had had in the United States with those who had led him to the conclusion that the very large hearth had not produced all the advantages expected from it.

Mr. F. Clements (Park Gate) said he had eagerly awaited Mr. Reese's paper, as it was by an author whose reputation was as high as his experience was wide. He had, however, to confess that after a very careful perusal of the paper he had laid it down with just a tinge of disappointment, not that he disagreed with any of the bases which Mr. Reese had laid down. Indeed he appeared to have re-stated what might be called the ten Commandments of blast-furnace work—"Commandments" in so far that all agreed with them intellectually as propositions, although they were not all keen on carrying them out. It was not quite clear how far the bases Mr. Reese had put before them were supported by his own experience. It might naturally be assumed that they were so supported, but the technical evidence was not given. All intelligent students of that very fascinating subject arrived early in their career at those hypotheses, but with the student they were only hypotheses. As the years went by the student encountered problem after problem, and in that experience he gathered together technical facts which went to prove or disprove the hypotheses from which he had started, and eventually he arrived at a position when he did not say "I think this is so," but said—in the manner and with the voice of the expert—"I know this is so." "I have proved it, here is my technical evidence." He did not know anyone in the iron industry to-day more able than Mr. Reese to give them that evidence, but unfortunately he had not done so in his paper, and hence his (Mr. Clements') disappointment.

There were three points in the paper which he wished to traverse. The first was relative to the breaking of stone. He was quite in agreement with Mr. Reese as to the logical argument on that point, but it was rather difficult sometimes to determine whether it was the right policy to follow, in view of the large capital expenditure involved. For instance, at the Staveley and Park Gate works, where at each plant the amount of ore handled was over two thousand tons per day, containing only 28 per cent. of iron, 1s. per ton added to the cost of the ore in handling it, would mean over 3s. per ton on the pig iron produced. That raised the question of whether the results made it really worth while doing, although it might be the strictly logical thing to do. He would very much like to ask Mr. Reese whether he had direct technical evidence of the value of breaking stone, and whether he had ever worked a furnace with unbroken stone, and then the same furnace with broken stone. What were the advantages in output, fuel economy, and general efficiency from a production point of view?

The second point was with regard to the value of gas cleaning. In his paper Mr. Reese gave eight specific advantages of gas cleaning.

He thought they were all familiar with those advantages and more or less in full accord with them. Mr. Reese stated that the economies obtainable far outweighed the cost of installation and upkeep. When, however, it was necessary to formulate a proposition it was difficult to determine the right type of filter to adopt.

He (Mr. Clements) thought the right design of gas cleaner had still to be evolved. In the meantime, what had Mr. Reese's experience been in the matter? Had he ever worked a plant with a gas cleaner, and again the same plant without the cleaner, and if so what were the advantages specifically covered within his experience? The third point to which he wished to refer had been touched on by Mr. Barrett. In his paper Mr. Reese laid it down as a general law that the output capacity of a blast-furnace was in proportion to the effective bosh area, and Mr. Barrett had called attention to the fact that the law had already been demonstrated in a paper which he (Mr. Clements') gave before the Institute in 1920. Based on considerable technical evidence he at that time arrived at the conclusion that the effective area of the bosh governed the output of the blast-furnace. In the autumn of that year, at the meeting of the American Iron and Steel Institute in New York, one of the speakers referred to his paper, and taking five examples from modern American practice, worked the data out, and proved again the truth of that general law and showed that for American practice the law held good just as it did for British practice. Therefore, as he was naturally interested in the matter, he would like to know by what technical evidence Mr. Reese had apparently arrived independently at the same conclusion.

Mr. E. C. Evans (London) said Mr. Reese's paper was valuable not only to those in the industry, but to those who were engaged in investigating fuel. He and his colleague, Mr. E. R. Sutcliffe, had been engaged in investigating the structure of coke in connection with its combustibility, and Mr. Reese's remarks on the preparation of materials were of considerable interest to them. Mr. Reese asked for a porous fuel which would burn rapidly and allow a considerable output; at the same time he referred in his paper to the fact that the reaction of carbon dioxide upon such a fuel in the blast-furnace was wasteful. Those two requirements were to some extent incompatible. Despite the weight of evidence behind it he (Mr. Evans) desired to join issue with that statement. His colleague and he did not think that the action of carbon and carbon dioxide in the upper portion of the furnace was wasteful. They considered that fuel which would give that reaction, far from being detrimental, was rather of the greatest benefit to the blast-furnaceman. Fuel of high combustibility was necessarily soluble in carbon dioxide. Charcoal, for instance, was far more soluble in carbon dioxide than coke. A charcoal furnace was usually of low capacity; it generally worked with low blast temperatures and, despite those disadvantages, it generally produced iron with a fuel consumption lower than any that had been obtained in the case of a coke furnace. If solubility in carbon dioxide were such a detriment, how could the work done in charcoal furnaces be accounted for? In one case Bell referred to a furnace that had been increased in height from 80 feet to 103 feet. The production per thousand cubic feet of that furnace diminished from 22 tons to 13 tons, and on an attempt being made to increase the relative production in the case of the larger furnace the fuel consumption immediately increased very considerably. The reason was that heat-producing reactions took place in the upper part of the furnace, resulting in increased sensible heat losses and practically in a transposition of heat from the lower part of the furnace where it was wanted to the top part where it was not wanted. What was Mr. Reese asking for throughout his paper in connection with the preparation of his materials: in connection with dry blast; with a blast working at as high a temperature as possible and with a low bosh? What was he trying to do? He was trying to concentrate the reactions of the furnace as near the tuyeres as possible. A highly combustible fuel would allow of that. The detrimental effects which had been observed with a soluble coke were not, in his opinion, due to the action of the CO_2 at all. He (Mr. Evans) and Mr. Sutcliffe had traced that idea right back through the proceedings of the Institute to the time of Sir Lowthian Bell himself. They had gone into the details submitted in support of that view, and they had been forced to the conclusion that such views as to a soluble coke were not proven. The disadvantages which Bell found were due not so much to the action of CO_2 upon the coke, as to the softness of the coke. It was a physical question and not a chemical one. They believed that a coke which was soluble in carbon dioxide would result in a considerable diminution of temperature at the top of the furnace, it would lower the zone of reaction in the furnace, and when it arrived at the hearth it would burn with such rapidity that the heat would be considerably increased. It was a question of combustibility which further depended on the structure of the coke. To perhaps a slighter extent the same thing applied to the ore. The question of the structure of fuel and ore was going to be of vital importance to the blast-furnace industry in the future. Mr. Reese spoke of briquetting and sintering. The structure of sintered ore was very different from that of briquetted ore. A sintered ore was dense and vitreous and had not the porosity that briquetted ore would have. The main factor was not so much the porosity of the materials as the character of the pores. Coke could be made of tremendous porosity and at the same time have a density equal to that of coal. Despite that density its porosity could be such that it could be made to burn quite easily in the ordinary way in the open grate. With a fuel of that character the possibilities in iron smelting were considerable. Iron had been made, smelted with charcoal, with a consumption of only 10·6 cwts. of carbon per ton of pig iron, and there was no reason why, with a coke of the proper description available cheaply and in large quantities, British furnaces should not, with suitably prepared ore, in the future produce iron with a consumption of only 10 to 12 cwts. per ton.

Mr. **Edward J. Duff** (Watlington) said he had made some experiments in connection with limekilns, the results of which might be useful to blast-furnacemen. Some years ago he had made experiments in producing high percentages of carbonic acid by burning limestone with coke in large iron-cased kilns, about 33 feet high, used in chemical works. He wanted to produce the highest possible percentage of carbon dioxide, and at the time he started the experiments he found he could not produce carbonic acid over 25 per cent. owing to the irregularity of the material. He then started breaking up the limestone and the coke to 4-inch squares or lumps. The bulk of the material was broken all to a regular size, and he found he could dump such material in either with the bell or without it, and that it distributed itself fairly easily and regularly. Eventually he succeeded in making a 38 per cent. gas with 1 to 2 per cent. variation night and day, week in and week out, and he reduced the coke consumption from about 3½ cwts. to 1½ cwt. per ton of lime burned. He thought those facts might have some bearing on the subject of grading the materials in the furnace.

Mr. **D. E. Roberts** (Cardiff), while thanking Mr. Reese for his paper, said he had nevertheless to confess to a feeling of disappointment with regard to it. He looked upon the paper merely as a kind of general account of the more or less agreed principles underlying modern blast-furnace practice, and he thought Mr. Reese had hardly done himself justice thereby. Mr. Reese was an able operator, and probably had as much experience of real blast-furnace work as anyone, and, that being so, he (Mr. Roberts) had hoped that he would have given the members something original, based on his own actual work.

He (Mr. Roberts) had just listened with considerable interest to what Mr. Evans had told them, and thought there were great possibilities in the methods he advocated. As far as he understood the matter, it was broadly Mr. Evans' aim to make, out of coal, a product structurally similar to charcoal. He had seen some of Mr. Evans' experiments before, and the results appeared most promising. He looked forward with interest to the development of that process.

Mr. **W. J. Foster** (Kenilworth) said Mr. Reese had dealt with what it was already known was necessary to obtain good results. In 1902 he (Mr. Foster) had gone thoroughly into the question of carbon in the hearth of the blast-furnace, and he had also investigated the question of the difference between the properties of coke and charcoal. They all appreciated that soft coke was attacked by carbon dioxide, but in using charcoal, which was also soft, they got good results in the blast-furnace. He proved in 1902 that it was the evolution of the gases from the charcoal which prevented to a great extent the action of carbon dioxide on the charcoal. In addition to that, charcoal was generally used in a blast-furnace with high-grade materials and in a smaller furnace which suited the adoption of such materials. He disagreed with Mr. Reese with reference to the density of the coke as regards its hardness in what might be regarded as modern practice. He appreciated the fact that good beehive coke had always been regarded as an ideal fuel for the blast-furnace in the past owing to its resistance to the attack of carbon dioxide. A coke should resemble a beehive coke as regards hardness, but should be of the densest possible character. Such a coke would afford a material which would offer the least surface resistance to the ascending gases, due to a proportionately less distance the gases would have to travel over its surface. Under those conditions the resistance could easily be reduced to something like two-thirds that of ordinary beehive coke. The next important question was that of slag. Mr. Reese told them that it actually took one-fourth of their coke to melt the slag made from 1 ton of pig iron. In 1904 he (Mr. Foster) wrote a paper on the thermal efficiency of the blast-furnace. He was dealing with a furnace using 29 cwts. of coke to the ton of pig iron. In making such pig iron 22 cwts. of slag were produced. It was estimated from the calorific value that the amount of coke required to effect complete fusion at the temperature of the slag leaving the blast-furnace at that particular time was 1·56 cwts. Any coke consumed in excess of that, under similar circumstances, would be loss due to inefficiency in practice. With reference to the question of grading the raw material, uniformity, as mentioned by Mr. Reese, was an all-important factor in the blast-furnace, but the question of cost of the grading of the raw materials was also one which had to be considered. He would give preference to the uniformity of coke and limestone, which was practically infusible until it reached the lower part of the bosh or hearth of the furnace, whilst the ironstone usually melted above the bosh line—which under certain conditions was the point of greatest resistance. The ironstone was melted before it was completely reduced, thus allowing space in the upper part of the furnace for the expulsion of the gases by reducing the mass and consequently the resistance at that point. It was not so important that the ironstone should be graded. In 1907 he had discussed Mr. Gayley's paper, and later discussed it with him in America. He pointed out to Mr. Gayley, when he contended in his original paper that by eliminating 0·7 per cent. moisture from the air he saved 4 cwts. of coke, while in his (Mr. Foster's) calculations, with the elimination of 2·5 per cent. moisture, the actual saving was only 168 lbs. On examining the figures Mr. Gayley agreed that that saving approached more nearly the mark as compared with that suggested by his German critics, and agreed that the advantage of the process was more particularly due to the regularity of the working of the furnace. It followed therefore that the greatest advantage derived from the use of dry air was when applied in inefficient practice.

Mr. J. H. HARRISON (Middlesbrough) said that Mr. Reese did not place any too much importance on the question of the distribution of the materials in the furnace, but he (Mr. Harrison) was rather at variance with Mr. Reese when he said that it was important that the moving materials should strike the stationary materials at about 18 inches from the walls, and that the bell diameter should be 4 to 5 feet less than the throat diameter. In his opinion the bell should be approximately half the area of the throat. As the material slipped off the bell into the furnace, it should not throw it far forward, but drop it more or less perpendicularly. Only the large pieces would roll over, leaving the small and fine where they first fell from the bell. In that way they got an annular ring of fine material, and they had the gases going up the inside and the outside of that annular ring of more or less solid material. Mr. Reese said the angle of the bell in some cases was 50°. In his opinion that was too steep. The larger pieces acquired velocity in rolling down so steep an incline and, falling heavily against the wall, destroyed the brick work. He thought an angle of 35° was much better. Mr. Reese stated that it was a well-known fact that the gases had a natural tendency to ascend next to the walls. Personally he very much doubted it, for the reasons he had stated. He thought the furnace walls really received rather a large amount of lumpy and large material. He quite agreed that the centre part of the charge descended more rapidly than the sides. That was due to the friction of the materials on the side walls. He could not see how it were possible that the bulk of the gases should find their way up near the side walls when they had a much greater opportunity of getting through the more open material nearer the centre of the furnace. Mr. Reese spoke of the heavy slip or explosion which blew off the furnace top or filled the tuyeres with slag. He thought that those were two quite different explosions (if they could call them explosions at all). The top slip was due to carbon deposition, and not to scaffolding, which was caused by the accumulation of fine material, mostly carbon, upon the bosh. The bottom slips were due to the falling away of the scaffolds. The top explosion was due to carbon impregnation, or the deposition of carbon on the oxide of iron, which began at a point some 6 feet down below the stock line. The carbon deposition extended for something like 10 feet. Within that space it had the effect of swelling the ore and causing it to jam against the side walls. It became a solid plunger in the upper part of the furnace. When it broke down it caused what was called a top explosion, owing to its descent compressing the gases under it until they burst through the materials. It had nothing to do, in his (Mr. Harrison's) opinion, with the charging of the ore into the furnace.

Mr. H. K. Scott (London) said that during the war he had been in touch with the production of Northamptonshire ironstone. Mr. Reese had used it during the same period in South Wales and found it difficult to handle owing to its unsatisfactory physical condition and, at times, high moisture contents. As that ironstone constituted the largest home reserve, he had hoped that the author would have made suggestions how best to treat it before use.

Crushing as referred to in the paper might serve for a hard lumpy ore, but would not suffice with the Northamptonshire mineral, as in the winter months it became so soaked with moisture that its associated colloidal material would clog any form of breaker.

Mr. Reese had not referred with sufficient emphasis to what he (Mr. Scott) would call the brutalising influence of civilisation. The waste of physical effort on some blast-furnace plants was distressing, and the men who would tolerate those conditions were passing. Others would only undertake that work in the future at much higher rates. He hoped that papers like the one under discussion would hasten the elimination of such undesirable conditions, which were a factor in industrial unrest. If any good results could be due to the late war they would be in making unskilled labour so expensive as to demand the installation of mechanical appliances to reduce it to small proportions.

Mr. C. H. Ridsdale (Middlesbrough) said he did not place as much importance on the word " modern " in the title as he did on the word " bases." The fundamental facts brought forward were not modern, but Mr. Reese had given a most excellent homily. It reminded him of the clergyman who was called to order for having preached the same sermon two or three times. His reply to the Bishop was that he was going to continue preaching that sermon until his congregation practised it. He hoped that Mr. Reese would go on hammering his theme until blast-furnace working was regularly carried out scientifically.

The smelting of ores was a chemical reaction and had to be considered all along from that point of view. First of all, the better the admixture the quicker the reaction. They all knew that if self-fluxing ore were used, it was only necessary for it to reach the right temperature and it melted, simply because the lime and silica were in intimate contact. Blast-furnace managers knew how they often found big lumps, both of limestone and especially of magnetic ores, down at the tuyeres. Over twenty years since he had had to tackle a blast-furnace problem, a recital of which might be appropriate.

Two plants were quoted to him and two sets of figures given. The burden of both was very similar, about 28 or 29 per cent. of iron in the mixture. One made 26 and the other 27 cwts. of slag per ton of iron. One, however, took only 21 cwts. of coke and the other 27—6 cwts. difference. In the one that took 21 cwts. the ore was broken to 4-inch cubes. He went thoroughly into the matter and prepared heat balance sheets which explained a great deal; and he thought every blast-furnace manager ought to be able to understand and work out heat balance sheets, otherwise he could not expect to get the best results. Without quoting the matter in detail, he might say that those showed that 1·2 cwt. of coke was saved by greater heat absorption in passing through the furnace, due to the greater surface of the broken stone, and 2·2 cwts. was saved by more thorough and uniform calcination without sintering. Thus altogether 3·4 cwts. coke saving was due to the use of broken stone. He was compelled to believe that the fuel, flux, and ore were best when in smaller pieces, of the size termed "rubble." He did not agree with what one member had said, inferring that when the author advocated small coke he meant dirty coke. He was sure he never meant dirty coke, but the use of clean-screened coke in pieces of 4 to 6 inches. He would like to live to see a plant worked with materials containing nothing smaller than about 1 inch, or larger than 5 or 6 inch pieces, uniformly screened and graded. One point not to be forgotten as regards the breaking of ores or coke was that the smaller materials screened off always contained a great deal of silica, besides other impurities proportionately, as compared with the larger. He had proved that repeatedly. Consequently it was not altogether loss to reject such smalls, although screening and breaking would cost something. He would like to ask Mr. Reese what ash there was in the coke that he said required 25 per cent. of its weight to melt the slag. That was, he thought, a different figure from that one of the members had quoted, namely that about 20 per cent. of the total fuel charged was used in melting the slag, when they had about 26 cwts. of slag to 1 ton of pig. Mr. Reese had said that coke "should be strong but not of great density." That appeared to be on the lines advocated by Mr. Evans, who had just spoken, and had also read two papers in which he advocated the use of porous coke of high combustibility, and predicted that under certain conditions Cleveland iron could be made with 12 cwts. of such coke per ton. He would like Mr. Reese or Mr. Evans to show, by a thermal balance sheet, how the use of coke that was more readily combustible (as charcoal was) would bring about reduced consumption.

CORRESPONDENCE.

Mr. E. Adamson (Sheffield) wrote that the discussion on Mr. Reese's paper clearly showed that the working of the blast-furnace was a question of physics rather than of pure chemistry, although the latter took its share in the process of smelting. The various speakers had brought out most of the points which could be raised in connection with the paper except that of *quality*, and it was satisfactory to note that with Mr. Reese's wide experience he laid great stress on that point.

It was difficult to theorise as to why an iron produced at low temperature was superior to one produced at a very high temperature, although it was generally accepted as a fact that steel, even when produced in an electric furnace at very high temperatures, had a crystallisation which it never entirely lost. There was nothing to show that that difference in crystallisation, which was also seen in cold-blast and hot-blast irons, was the cause of the difference of the quality of the pig iron, but again statements of fact showed that there was a distinct difference. It was probably only necessary to mention two cases which had come to his notice. One was that of a small blast-furnace worked at comparatively low temperatures, and the steel produced from that iron was admitted to give better results of tests, &c., than those obtained from iron of practically the same analyses but from a furnace producing three times the quantity and also working at a very much higher temperature. The other case was of a blast-furnace supplying metal to their own steelworks, where it was found that the steel gave better tests when the temperature of the blast-furnace was reduced by 200° F. Those two facts suggested that working blast temperatures at 1400° F. would be at the expense of the quality of the pig iron and hence of the steel.

Personally, he was more interested in *quality* from the point of view of foundry pig iron, where a totally different set of conditions existed than in the manufacture of steel, for whilst chemical composition of the steel was the chief thing aimed at there was no refining or elimination of impurities from the virgin pig iron in the foundry, and therefore the fracture of the pig iron was of material consequence. It was well known that cast iron of practically the same analyses cast into test-bars as nearly as possible under the same conditions gave widely different results. Differences of 18 to 9 tons tensile had been obtained from the same sized bar and with the same analyses, the higher results being obtained from cold-blast and semi-cold-blast, whilst the lower results were obtained from hot-blast irons.

Crystallisation *per se* might have something to do with the difference, but it did not entirely account for it, and whilst in the steel world for international competitive reasons it might be necessary to aim at output, providing the quality was only slightly affected, for foundry irons it was wise to look to quality and work the furnace accordingly.

Mr. J. Calderwood (London) wrote that he was in agreement with nearly everything in the paper, except what was said as to gas cleaning. Mr. Reese enumerated the advantages of clean gas, eight in number. The only one of the eight to be obtained from rough cleaned gas was the last, and that could be reached by the use of efficient dust-catchers without the expenditure of a lot of money on a cleaning plant. In his opinion, the only way to clean gas was to clean it thoroughly, for in no other way could the full advantages and economies specified by Mr. Reese be obtained.

1. There was really no rough gas cleaning which could be called a success, certainly there was no such plant which removed the objectionable fume, and if that were not removed, the advantages became nil. The gas had to be cleaned as if it were for use in gas-engines, and the only plant to do that effectively was the Halberg-Beth.

2. With rough cleaned gas the saving of time and labour was very problematical. With only 5 grammes per cubic metre there would be at least 50 tons of very objectionable dust passing through the hot-blast stoves per annum.

3. Rough cleaned gas failed altogether to give that economy. The fine dust and fume left were the most destructive to the stove brickwork.

4. The same remark applied here as in No. 3.

5. That was subject to the same objection as No. 2.

6. It seemed to him (Mr. Calderwood) rather futile to use smaller checker openings with gas only partially cleaned. It was only adding opportunities for fluxing and choking.

7. The higher stove efficiency was, of course, based on the improved brickwork with clean gas, and full efficiency was only obtained if the gas were thoroughly cleaned.

8. That advantage, as already remarked, could be obtained by the use of the dust catchers without a rough gas cleaning plant.

In conclusion, he wished to emphasise his opinion that there was no satisfactory rough cleaning plant, and that the only way to deal with blast-furnace gas was to clean it thoroughly. The electrostatic plant had not yet been developed to a reliable and satisfactory point, and the only really efficient plant in use was the Halberg-Beth dry cleaner.

Mr. Reese, replying to the discussion, said Professor Louis had referred to the question of output and economy and expressed disagreement with the view that the greatest output consistent with quality was the object of modern blast-furnace practice, his idea being that a low fuel consumption or fuel economy was incompatible with large pig iron outputs. He thought if Professor Louis would consult some of the results obtained in recent years in the United States with furnaces making upwards of 700 tons, he would find that the fuel consumption ran as low as fuel consumption in Great Britain under the old practice, if not a good deal lower. Within the last few months details had been published in trade papers of the results from one of the most recently built blast-furnaces in the United States, in which the fuel consumption was 16 or 16½ cwts. with daily outputs of 700 and 800 tons of pig iron. Professor Louis spoke of enormous furnaces, but the furnaces in which such practice was carried out were not enormous furnaces. They reached 85 to 95 feet in height, and a few were 100 to 105 feet high. The latter practice had died out, and 85 to 95 feet was now the standard size for modern blast-furnaces. There were many furnaces under the old practice that were 85 feet in height, and some higher. There was nothing, therefore, very enormous about modern furnaces. The internal volumes of those furnaces were a good deal smaller than those of the 85 to 95 feet furnaces under the old practice, as they were now much smaller in diameter, except at the hearth. There was no doubt that large output had a very decided effect on economy because it reduced fixed charges, labour, and other costs, except the cost of raw material and fuel, while under the new practice the fuel consumption was certainly as low, if not lower, than under the old. Professor Louis was wrong in stating that he (Mr. Reese) advocated as a necessary feature in modern practice the "large outputs, say 600 tons per day," though he certainly did strongly advocate the principles upon which such outputs were, under certain conditions, and with certain materials, obtainable. He doubted the possibility of producing 600 to 700 tons per day with any of the materials usually employed in Great Britain, excepting some of those on the west coast, but by the adoption of the principles outlined, outputs from 350 to 500 tons were economically possible. He would venture to say that if those principles were generally put into practice, the required national output of pig iron would be produced more economically, and with one-third or less of the blast-furnaces from which it was now obtained. With regard to the size of the ore, the usual practice was to break it down to 3 inches, the extent depending somewhat on the characteristics of the ore. An ore such as dense magnetite or dense hæmatite could be usefully broken down even smaller, to 2 inches. In his opinion and experience, an ore which was a quarter of an inch in size would work well in the blast-furnace, and would, therefore, require no preliminary treatment. It was the fine dusty material that caused the difficulty.

In reply to Mr. Barrett, magnetite ore would, of course, be crushed before being subjected to the roasting process. That method of treating magnetite ore was formerly carried out at the Wharton Furnaces at Wharton, in New York State. If Mr. Barrett would read more carefully the section of the paper on "The Flux," he would note that he (Mr. Reese) clearly stated that the limestone or dolomite should be broken in a similar manner, and for similar reasons, as applied to the ore. With the very high-blast temperatures there was originally some difficulty experienced with the warping of the hot-blast valves, as they were not water-cooled, but by increasing their thickness and making them of a better quality of iron, that trouble was considerably reduced. There would be no difficulty with water-cooled valves and seats.

He regretted that Mr. Clements and Mr. Roberts were disappointed, his paper not having been such a one as they desired, or had hoped for. Mr. Clements raised the question of his not having given data of his experience. The paper was not meant to be a treatise on blast-furnace operation, but an outline of the bases of modern practice. The discussion of the paper had already lasted a long time, and if he had written such a treatise it would probably have taken a week to discuss it. The facts recorded were the result of some thirty years' experience in blast-furnace work—experience, observation, and a certain amount of common sense. He had no masses of statistics with which to satisfy Mr. Clements, and he would not say he could confirm by definite figures from his personal experience all the various facts which he had given or the statements he had made as facts. But as he said, they were based on experience, observation, and common sense. There was a saying that the fool learned from his own experience, and the wise man from the experience of the fool. While he (Mr. Reese) undoubtedly had been such a fool to some extent, he hoped and thought he had had some of the wisdom which had enabled him to learn from the experience of other fools. He recommended Mr. Clements to adopt that principle, and not to think that the only things he knew anything about, or that anybody else knew anything about, were the things that he, or they themselves had done. Mr. Clements had stated that as it took at his works 3 tons of ore to produce 1 ton of pig, it would not pay him to spend 3s. per ton of pig to crush his ore. From his (Mr. Reese's) knowledge of the mechanical condition of that ore as mined, it would have to be crushed if he (Mr. Clements) was going to adopt modern practice, and he could assure Mr. Clements in that case the 3s. he mentioned would be returned to him several fold. Of course, if he did not want to adopt modern practice, he had better go on as he was, though even with his present practice it would probably pay him to crush his ore. He might say for Mr. Clements' satisfaction that he had worked a furnace alternately on broken and unbroken ore, and the beneficial results from the former were so marked that he was sure they would have astonished Mr. Clements. With regard to gas cleaning, so much literature had been published on that subject with convincing data as to the economy, that he was rather surprised that Mr. Clements still required further information.

Mr. Evans had suggested the possibility of a very radical change in the economic production of pig iron; a change so radical, and in respect of which his claim was so enormous, that it was beyond the scope of the present discussion. He (Mr. Reese) would suggest to Mr. Evans that the proper thing for him to do, having confidence in his convictions, was to produce a sufficient quantity of his "char coke" (as he would term the new material) to test it properly in a blast-furnace. He would recommend that Mr. Evans should do that in a blast-furnace operated under modern conditions, and not in one of the older type which was operated by pressure under the older practice. By that means Mr. Evans would get some conclusive results which would confirm his convictions or otherwise.

Mr. Foster had referred to a statement in the paper "that it took approximately a quarter of the weight of fuel used to take care of the slag." The statement was not that a fourth of the coke in the furnace was required to take care of the slag, but that 25 per cent. of the weight of the slag produced was required in coke—though he should have said carbon instead of coke. How much coke was actually required depended on how much slag there actually was. With regard to Mr. Harrison's remarks about the size of bell, and the distribution of ore in the furnace, the figures given in the paper were the general practice in the latest designed furnaces which had done the work referred to. There was a difference of 4 or 5 feet between the diameter of the bell and the diameter of the furnace at the stock line. With regard to the filling of the material within 18 inches of the wall, he took it that Mr. Harrison wanted the fine material to be about half-way between the centre and the wall, which would give him a great deal of lumpy material on the walls. He entirely disagreed with that, because, as he had stated (and he believed it to be a fact), there was a tendency for the gases to follow up the walls if they could, and, therefore, there should be something to prevent that tendency. He had had experience of that in charging a furnace, when only lumps were put upon the wall, and the result of that experiment was that practically all the gases went up along the walls, and the furnace not only made bad iron but made it badly as well. Mr. Harrison seemed to have inferred that with the bell system of charging the gases did go up along the walls. If the material were of uniform size throughout the gas would tend to go up near the walls rather than through the centre of the furnace, and that method of charging owed its success to the fact that it did place a certain amount of smaller material on the walls, which tended to counteract that tendency of the gases, and improved their distribution throughout the cross-section of the furnace.

Mr. Duff's experience in lime-burning with broken stone and coke was very interesting, and the better results he obtained were doubtless due to the same reasons as those outlined for breaking the materials charged into the blast-furnace.

With regard to the Northamptonshire ore mentioned by Mr. Scott, and the difficulty he would anticipate in crushing it in winter, he (Mr. Reese) was inclined to think Mr. Scott was either referring to some particular mine or district, for it was quite within his (Mr. Reese's) knowledge that such deplorable conditions did not exist throughout that ore field, nor in any considerable portion of it, and he was rather of opinion that in all probability where they did exist they were due to bad mining or quarrying arrangements. However, there should not be any difficulty in passing such material as that described by Mr. Scott—a mixture of colloidal material and lumps—between a pair of high-speed crushing rolls.

Mr. Adamson had raised a very interesting point in referring to the variation in the quality of steels made from high and low temperature pig irons. He (Mr. Reese) had made many thousands of tons of pig iron with blast temperature from 1400° F. to 1550° F. Much of this iron had been converted into steel for purposes for which quality was of the first importance, such as boiler, cold-flanging, and high tensile plates, ship plates, rods for screw making, rails, &c., and much of it had been used in foundries throughout the Midlands and South Wales. No suggestion had ever been made by any users of that iron that the quality of their products had been detrimentally affected by its use. On the contrary, there had been instances of quite the reverse. In face of the facts referred to by Mr. Adamson, it would seem there must be some counteracting influence in connection with the iron first mentioned which nullified the detrimental effect of the high-blast temperature used in its production. Accompanying the high-blast temperature, there was another unusual feature. That iron was made with dry blast, not high-temperature blast, but high-temperature *dry* blast. Mr. Adamson had rightly said it was difficult to theorise on such a subject, but might it not reasonably be assumed as a possibility that the "counteracting influence" in that case was dry blast. If so, that furnished a further hitherto uncredited benefit from dry blast.

If Mr. Calderwood were correct in his premises that the "rough" cleaned gas referred to in the paper contained anything like 5 grammes of dust per cubic metre, he would be equally correct in his opinion as to the futility of "rough" cleaning blast-furnace gas, and he (Mr. Reese) would heartily agree with him. He was, however, wrong in his premises. It was hardly likely that anyone in his senses would install a plant for cleaning blast-furnace gas down only to 5 grammes per cubic metre, or 2·2 grains per cubic foot. By "rough" cleaned gas reference was meant to gas cleaned down to ½ grain per cubic foot, or 1·14 gramme per cubic metre. Perhaps he should have mentioned that figure in his paper, but he thought that by the term "rough cleaned" it would have been sufficiently indicated to those who would be acquainted with and interested in the subject. On the basis of ½ grain per cubic foot the "rough" cleaned gas would retain only the most impalpable portion of the fumes, most, if not all, of which would pass through the stoves and out at the top of the chimney with the waste gases. In those circumstances, the "50 tons of objectionable dust" mentioned by Mr. Calderwood dwindled to a very insignificant matter (hardly sufficient to destroy the seven advantages stated by the author, but disallowed by Mr. Calderwood as obtainable with "rough" cleaned gas), to avoid which it would seem hardly worth while to incur the great additional cost of cleaning the whole of the gas down to gas-engine purity, 0·002 gramme per cubic metre.

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AN INVESTIGATION ON THE FACTORS INFLUENCING THE GRAIN AND BOND IN MOULDING SANDS.

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PART I.

Introduction.

This investigation was undertaken with a view to estimating quantitatively the effect upon the essential properties of the sand of the various processes to which moulding sands are subjected. The essential properties that fall within the scope of this research are: (*a*) the strength of the bond; and (*b*) the ratio of the various mechanical grades, which is the determinant of the venting properties of the sand.

Whilst refractoriness is undoubtedly a factor of the greatest importance, even in sands for grey iron castings, it is obviously so slightly affected by the method of preparation, or any of the conditions here investigated, that it will not be discussed in this research.

In foundries where there is no technical control, sand is treated in either of the following ways, depending upon economic conditions, with a view to maintaining a workable bond in the sand.

(*a*) In districts where a good supply of well-bonded moulding sand is available, the old sand is strengthened by means of an addition of from 10 per cent. to 50 per cent. of new moulding sand.

(*b*) In those areas where good moulding sands are expensive, owing to their distance from the foundry, it is usually the custom to replace the burnt-out bond by means of additions of 5 per cent. to 25 per cent. of "loam"; that is, a fine-grained sand having a high clay content and usually containing much silt.

Mechanical mixing is resorted to in the larger foundries in many cases; but in others, especially where "loam" is used, the mixing is done by hand.

Mechanical mixing may be effected by the following means, placed in order of general usefulness:

1. Pug mills and edge runners (pan mills).
2. Disintegrators.
3. Paddle mixers.
4. Mechanical riddles.

In foundries where technical control is in operation, consignments of moulding sand are usually subjected to bulk chemical analysis in which the content of iron and alumina are frequently reported together and the alkalies are estimated by difference. Such an analysis yields very little useful information as to how the sand will behave under foundry conditions.

Mechanical grading, when carried out, does not usually involve preliminary deflocculation. Thirty, sixty, and ninety mesh sieves are used; not only is this test incomplete, but the size of particle passing the various sieves depends so much upon the gauge of wire with which the sieve is made, that results are not comparable.

The thanks of the foundry industry are due to Professor Boswell in this country, and to Moldenke, Outerbridge, Lane, Hanley, Simmonds, and others in America for having introduced greater refinement into the testing of moulding sands.

The present investigation is the commencement of an attempt to correlate the various lines of research which these workers have followed; it is based on three years' routine testing, during which time methods and apparatus have been so adapted as to yield accurate and concordant results. It is hoped, during the next few years, to extend the work very considerably; more especially in examining more fully the influence of those variants discussed here, in investigating the effects produced by factors not yet considered, and in correlating the results obtained over a wider range of sands.

PART II.

Description of Apparatus.

(*a*) The mechanical tests were carried out on a machine specially constructed for the purpose with a view to applying small loads, of the order of a few hundred grammes, with an entire absence of shock, and at a definite rate in grammes per second. The machine consists of a beam 12 inches long, resting in its centre upon steel knife edges, and having similar knife edges at either end which work in hardened steel shackles. From one shackle is suspended a vessel capable of holding 2 litres of water; from the other an arrangement, as shown in Fig. 1, is suspended. This consists of two triangular pieces of mild steel, A A, connecting the two side pieces, B B, to the shackle. The side pieces support either the breaking bar D in the transverse test, or a flat plate in the compression test; and the tray C, which carries weights to balance, approximately, the weight of water on the opposite arm. The position of the transverse test-bar is shown at T (Fig. 1).

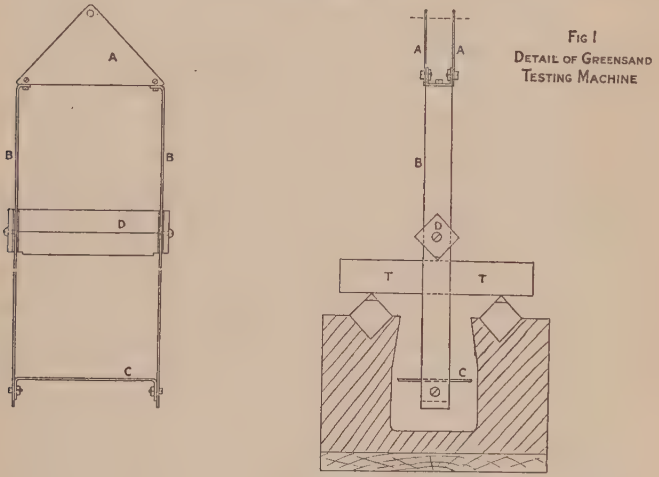

Fig. 1.

For the transverse test two square bars are set in a wooden frame, parallel to the breaking bar and equidistant from it, having their centres 4 inches apart; in making compression tests a flat plate is laid over these bars and the piece is crushed between this plate and another plate fixed between the side pieces in place of the transverse breaking bar. Sufficient water is run into the vessel to overbalance the weights on the tray C, &c., and the test-piece is placed in position.

Water is now syphoned gently out of the vessel until the beam is floating. A measuring cylinder is then placed under the syphon, and water is allowed to run from the vessel to the cylinder by means of a spring-clip until the test-piece fails; the spring-clip is immediately shut off and the volume of water in the measuring cylinder gives directly the breaking stress on the bar in grammes.

The transverse bars are rammed up in a hard-wood core-box with loose sides and loose recessed ends 6″ × 1½″ × 1″, and compressed by means of a wooden top piece having a projection 6″ × ½″ × 1″ to the final size 6″ × 1″ × 1″. The compression pieces are made in a brass boss 1½ inches high, having a ⅝-inch round hole in the centre, and are compressed by means of a small screw press and a ⅝-inch plunger to 1 inch high by ⅝ inch diameter. They are then readily pushed from the boss.

(*b*) Mechanical grading was effected by means of a rotary shaking machine for deflocculating the sample, a Crook's elutriator, and a set of metric copper sieves with punched holes as prescribed by the Institute of Mining and Metallurgy. The elutriator is of the standard Crook type and dimensions for separating the sand grade, 1 millimetre to 0·1 millimetre; silt grade, 0·1 millimetre to 0·01 millimetre; and clay grade, less than 0·01 millimetre. An additional jet is used for separating the fine and coarse silt, dividing at 0·05 millimetre. The following refinements have been found essential in work where considerable accuracy is required.

The water, during cold weather, is passed through a glass coil in a bath of warm water, and then through a bottle containing a thermometer, so that all tests may be made using water at 15° C. The sand-grade tube is clamped rigidly in an absolutely vertical position to prevent the coarse silt sliding down and being estimated as sand grade. The rubber tube connecting the constant pressure head and the sand-grade tube has, with the exception of 2 inches of rubber, been replaced by glass. This was done to avoid the errors caused by pieces of flocculent material being washed off the inside of the rubber and causing trouble in the elutriator; also, should the water pressure fail during a test, sand falls back into the rubber tube, sticks to this degraded surface, and is lost so far as the test is concerned.

For the bond adsorption test a rotary shaking machine has been made. It consists of a wooden disc 1 inch thick and 1 foot 3 inches diameter mounted on a central spindle, and worked by a friction drive direct from the shaft of a ½ horse-power motor. The rotating speed is 50 revolutions per minute, and the machine is so arranged that one, two, or three bottles may be rotated at once without unbalancing the disc.

The mill used for milling the sand is an edge runner of the usual type, and of the following dimensions:

Diameter of pan, 6 feet.
Diameter of rollers, 3 feet 6 inches.
Width of roller faces, 12 inches.
Weight of rollers, 6 cwt.
Speed of pan, 25 revolutions per minute.

One of the rolls is plain and the other toothed; two distributor plates are fitted to bring the sand under the rollers. The disintegrator is of the horizontal type, the disc 24 inches diameter and the speed 750 revolutions per minute. No special apparatus was used in the casting experiments; such as was used is described in Part III. to avoid repetition.

PART III.

METHODS EMPLOYED.

After many experiments in ramming up test-bars of sand the most consistent results were obtained by tempering the sand to a moisture content of 7·5 per cent. and ramming up a definite weight of sand by means of the following standardised series of operations.[1]

For the transverse test, 180 grammes of sand were taken; the sand was filled lightly into the assembled core-box until level with the top and pressed down by ten light strokes with a spatula handle. The remainder of the sand was filled in and the process repeated. The top was then placed in position, pressed down by hand, and driven home by ten strokes of a hand hammer.

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[1] R. J. Doty, *Proceedings of the American Foundrymen's Association*, 1922, records the fact that volumetric methods for the measurement of sand for test-bars have been superseded by gravimetric methods, and more concordant results have been obtained thereby.

The compression pieces were made by compressing 8 grammes of sand to the required volume in the mould by means of a screw press.

Stronger bars than those used in these tests can be made by increasing the weight of sand per unit volume of the test-bars; they have not, however, given such reliable results as have the bars prepared in the above manner. The use of a small pneumatic squeezer is under consideration as a refinement of the above method.

The method of breaking the test-pieces has been described in Part II.

The samples were prepared for elutriation by taking 10 grammes of the sample, previously dried at 110° C., and passing it through a 1-millimetre sieve. Any residue remaining on the 1-millimetre sieve was examined and any grain aggregates were crushed between the fingers and returned to the sieve; any final residue on this sieve was weighed.

The sample sieved to 1 millimetre was transferred to a 500 cubic centimetre stoppered bottle, 250 cubic centimetres of water, and 5 cubic centimetres of a 10 per cent. ammonia added, and shaken for an hour on the rotary shaking machine in order to deflocculate the clay. Eight to ten litres of water were usually found to be sufficient to remove the clay grade from the elutriator, which was collected in litre-graduated cylinders (this afforded a running check on the rate of elutriation, which was kept steady at 100 cubic centimetres in ninety seconds), and allowed to settle out in Winchester bottles. Five minutes before the end of the test, the clip between the sand and the silt vessels was partially closed to avoid the coarse silt running back into the sand vessel. In the case of a sand such as Mansfield, where a large percentage of the grains vary between 0·15 millimetre and 0·08 millimetre, this precaution is very necessary.

The silt grade was elutriated into two grades, 0·10 millimetre to 0·05 millimetre and 0·05 millimetre to 0·01 millimetre after removal of the sand grade from the lower vessel, by means of a different head and jet; working at 27·5 cubic centimetres per 100 seconds. The bulk of the water was decanted from all grades, which were subsequently dried at 110° C. and weighed. The sand grade was then divided on the sieves and the fractions weighed.

The bond adsorption test was carried out after the method of Hanley and Simonds. From 10 to 20 grammes of sand, depending on the bond, were weighed into a 500 cubic centimetre stopppered bottle and rotated for an hour with 250 cubic centimetres of distilled water and 5 cubic centimetres of 10 per cent. ammonia. A solution of acetic acid, of such strength that 5 cubic centimetres rather more than neutralised the ammonia were added, and sufficient crystal violet dye (to give at least 40 milligrammes excess after adsorption) dissolved in 100 cubic centimetres of distilled water. Any dye remaining in the beaker was rinsed into the bottle with 40 cubic centimetres of water (making a total volume of 400 cubic centimetres) and the bottle shaken for a further two hours. After standing for some hours, 100 cubic centimetres of the clear liquid was drawn off, 2 cubic centimetres of 10 per cent. acetic acid and 25 cubic centimetres of water added, and the excess of dye was removed by introducing a 5-gramme hank of mordanted cotton yarn, the temperature being gradually raised to 60° C. After the whole of the dye had been removed from the solution, the yarn was withdrawn, washed, and dried at 75° C. This hank was then compared with a series of similar ones, on each of which a standard weight of dye had been deposited. From this the weight of dye adsorbed by the bond of the sand is calculated.

The analyses were made on 0·5 gramme of the finely ground sample. Loss on ignition was determined, and a fusion effected by heating the residue with 5 grammes of fusion mixture.

Silica was separated by two extractions; the yield of silica obtained on taking the filtrate from the first residue to dryness being usually of the order of 0·6 per cent.

Iron, alumina, titanium, and phosphorus were separated by precipitation on ashless pulp fibres with ammonia. From the weighed residue, iron was estimated by stannous chloride and di-chromate and the alumina as phosphate. Lime was precipitated as oxalate and estimated volumetrically with permanganate. Magnesia was weighed as the pyro-phosphate. The alkalies were determined by the Lawrence-Smith method and separated by perchloric acid.

The casting tests were made in the following manner: Three circular moulding boxes, each 4 inches deep and 1 foot 6 inches in diameter, were taken. One of them was rammed up with floor sand and dried; over this was placed a disc of 30-mesh iron gauze 18 inches diameter having a 3½ inch hole in the centre.

A second box was placed upon the gauze and rammed up with the sand under investigation round a cylindrical pattern 8 feet long, 3 inches diameter, placed in the centre of the box. A good joint having been made, straight wires of tin, lead, zinc, aluminium, and silver, each exactly 6 inches long, were laid radially along the joint and touching the pattern, filling an angle of 60°. The third box was now put on, rammed up, the position of the wires marked on the box, and the metal was poured into the green-sand mould. The object of the dry-sand drag and the wire gauze covering was to provide a solid foundation for the mould without risk of contamination of the sand whilst on the foundry floor or whilst taking the samples of sand from the mould after casting.

The samples of sand were taken, after the mould had cooled down, as follows:

The sand up to half an inch from the face of the casting was isolated by pressing down through the sand a cylinder of tinned sheet. About 90° of the cylinder was cut away and ½ inch of edge turned in at each side, so as not to cut the wires. The samples at 1 inch, 2 inches, and 4 inches from the face of the mould were taken by means of a tinned sheet tube 1 inch diameter.

When all tube samples were taken and transferred to their respective tins the casting and sheet metal casing were removed, the sand transferred to its container, the wires carefully dug out, and the length over which they had melted was measured.

PART IV.

ORIGIN AND NATURE OF THE SANDS USED IN THE INVESTIGATION.

The Mansfield sand used was the variety known as "best moulding," and was obtained from the pits unmilled. Consecutive consignments of this sand have shown great regularity in grain, size, and bond. It is typical of the best Bunter moulding sands, combining good venting properties with a fine grain and an excellent bond; also it is more refractory than many of the Bunter sands, being less micaceous. In addition it possesses that "silky" texture which gains the confidence of the moulder, a matter of prime importance.

The Heck sand also occurs in the lower Bunter formation, but is more comparable to the Worksop deposit or to the coarser beds overlying the Mansfield "moulding sand." It is reddish-orange in colour and contains a fair amount of Muscovite.

The South Cave sand was the variety known as "South Cave Red." It is dark brown in colour and has, especially when its mechanical analysis is considered, a most remarkable bond. The peculiar stickiness of this sand is quite unique in the author's experience of English moulding sands. It is apt to be nodular and is not easy to sample accurately. Its chemical composition is sufficiently good to permit of its use as a bonding material in steel moulding. The mixture of Heck and of this sand is used, mixed with an equal amount of old sand, as a facing sand for green-sand work with great success. It occurs in the Jurassic System (Kelloway Beds).

The silica sand is a second-grade sand of unknown origin and is normally used solely in the making of "oil-sand" cores.

The refractory clay used in the "silica sand and clay" mixture was obtained from the Yorkshire Amalgamated Products Ltd.'s sand pits between Castle Howard and Huttons Ambo. These beds lie in the Lower Oolites, and the clay is found overlying well-defined beds of high-silica and kaolin-bearing silica sands of considerable purity and of widely differing mechanical characteristics. It would be more correctly classed as a strong loam than as a clay. As will be seen from the bond adsorption figure, the clay grade is very "fat"; much more so than the kaolin bonding the sands beneath it. Unfortunately only sufficient was available for one test, which was made by adding the clay, ground dry, to the sand in the mill and tempering during milling. Had more been available, a second trial would have been made, adding the clay as a slip, which would probably have been more successful. In any case, the coating of smooth grains of silica with clay by mechanical means is a difficult and unsatisfactory proposition.

The Durham sand is of glacial origin. Both as considerable deposits and in isolated pockets, these sands are widely distributed in County Durham. The author has examined many samples varying from coarse bondless sands to silty loams containing up to 20 per cent. of clay grade. Whilst they appear to be fairly useful from the bulk analysis, they are almost always badly sorted as regards mechanical grading and consequently vent poorly. The bond is composed of a rather lean clay which burns out quickly, and the sand has a strong tendency to burn on to the casting. These glacial sands are widely used in the Tyne-Tees area, and their continual deficiency of bond is made good by additions of Erith or similar loam. The author believes, as regards the above district, that more defective castings are attributable to this practice than to any other single factor.

PART V.

CONSIDERATION OF THE RESULTS OBTAINED.

Amongst the new data presented in this report there is much that is difficult to interpret; there are also points upon which it is unwise to be dogmatic in view of the lack of data upon moulding sands in general. Some, however, of the results obtained afford new and quantitative data which should be of service to the ironfounder.

Examination of the mechanical analyses shows a considerable and progressive degradation of grain size during the preparation of the sand. This degradation becomes more considerable when it is borne in mind that in practice the sand is milled several times during its useful life, and that the increase in grain size, which, contrary to expectation, was observed in each case after casting, must be apparent only, and due to causes which will be discussed later.

The Mansfield series (Fig. 2 (Plate I.) and Table I.) is the most complete, and, as each curve is the mean of at least two elutriations, it is probably the most accurate. It is also the most easily interpreted. This sand, being fine grained, has a large surface over which the bonding matter must be spread, hence it is fair to assume that this coating is thin enough to be affected almost throughout its depth before milling by the process of deflocculation, even though it may not be entirely removed from the enclosed sand grain. This contention is strongly supported by the comparatively slight increase in the bond adsorption value on milling the sand. Considerable light is thrown upon the high mechanical strength of the sand, and on the increase of strength on mechanical treatment by examination under a good hand lens × 7, and a low power microscope × 35.

TABLE I.—*Mechanical Analyses—Mansfield Sand.* (See Fig. 2.)

Grade.	Diameter in Millimetres. Grade Size.	Raw Sand.	Milled 2 Min.	Milled 5 Min.	Milled 10 Min.	And Disintegrated.	After Cast. 0″–½″.
Coarse sand .	1·0 –0·5	0·50	0·55	0·50	0·50	Nil	0·30
Medium sand	0·5 –0·25	2·43	2·00	2·30	1·80	2·20	3·90
Fine sand .	0·25–0·10	70·77	69·65	64·00	63·50	59·80	66·20
Coarse silt .	0·10–0·05	16·70	17·15	20·80	21·10	19·50	21·80
Fine silt .	0·05–0·01	1·27	1·80	2·00	2·20	5·00	1·60
Clay . .	less than 0·01	8·33	8·85	10·40	10·90	15·40	6·20
Total . . .		100·00	100·00	100·00	100·00	101·90	100·00

In the raw state the sand is seen to contain many clusters of grains which hold more than the average quantity of bonding material—and apparently the bulk of the fine silt as well—leaving less than the average amount for distribution over other grains; the points of contact between these latter grains being the weak link in the chain. Even after an hour's deflocculation and two hours in the elutriator, the grains retain their red tint due to a very thin pellicle of ferric oxide, which, in view of its

Table II.—*Mechanical Analyses—Heck and South Cave Sands.* (See Fig. 3.)

Grade.	Diameter in Millimetres. Grade Size.	Raw Heck.	Raw S. Cave.	Raw Mixture.	Milled 10 Min.	And Disintegrated.	After Cast. 0″–½″.
Coarse sand .	1·0 –0·5	1·40	5·50	2·90	1·50	0·70	1·80
Medium sand	0·5 –0·25	43·60	51·20	45·70	41·00	40·40	47·60
Fine sand .	0·25–0·10	45·35	26·05	36·70	37·50	35·00	36·00
Coarse silt .	0·10–0·05	4·25	2·20	2·50	6·30	9·80	5·45
Fine silt .	0·05–0·01	0·50	1·75	1·30	1·30	2·00	1·45
Clay .	less than 0·01	4·90	13·30	10·90	12·40	12·10	7·70
Total . . .		100·00	100·00	100·00	100·00	100·00	100·00

Table III.—*Mechanical Analyses—Silica Sand and Clay.* (See Fig. 4.)

Grade.	Diameter in Millimetres. Grade Size.	Silica Sand.	Clay.	Raw Mixture.	Milled 10 Min.	And Disintegrated.	After Cast. 0″–½″.
Coarse sand .	1·0 –0·5	Nil	0·40	0·65	0·60	0·15	0·50
Medium sand	0·5 –0·25	7·60	1·45	12·45	6·80	11·90	10·00
Fine sand .	0·25–0·10	91·20	36·55	72·90	77·20	72·25	79·00
Coarse silt .	0·10–0·05	1·00	34·70	7·10	6·70	4·90	6·30
Fine silt .	0·05–0·01	0·20	5·40	1·00	1·10	1·10	0·70
Clay .	less than 0·01	Nil	21·50	5·90	9·60	9·70	3·50
Total . . .		100·0	100·00	100·00	100·00	100·00	100·00

Table IV.—*Mechanical Analyses—Durham Sand.* (See Fig. 5.)

Grade.	Diameter in Millimetres. Grade Size.	Raw Sand.	Milled 10 Min.	And Disintegrated.	After Cast. 0″–½″.
Coarse sand . .	1·0 –0·5	3·00	2·45	0·50	1·75
Medium sand .	0·5 –0·25	8·55	5·30	6·40	8·35
Fine sand . .	0·25–0·10	53·45	51·85	52·35	60·50
Coarse silt . .	0·10–0·05	21·20	25·85	28·00	20·80
Fine silt . .	0·05–0·01	7·75	7·10	4·55	5·75
Clay . . .	less than 0·01	6·05	7·45	8·20	2·85
Total . . .		100·00	100·00	100·00	100·00

resistance to solution in hydrochloric acid, would appear to be dehydrated and incapable of adsorbing dye.[1]

The bond then would seem to exist in two forms :

1. The mobile or hydrated bond which is capable of transference from grain to grain, and

2. The static bond which is fixed to the surface of the sand grains, forming a hold upon which the mobile bond may be evenly spread and displayed to the best advantage for mechanical strength. This static bond, common to all Bunter moulding sands that the author has examined, although small in amount, certainly has a greater tendency to strengthen the sand than would a similar amount of mobile bonding material coupled with smooth grains of silica.

TABLE V.—*Grade Chemical Analyses—Mansfield Sand.*

Grade.	Fine Sand.	Coarse Silt.	Clay Grade.
SiO_2	85·96	74·74	37·26
Fe_2O_3	1·24	0·94	3·44
Al_2O_3	6·26	7·28	18·32
CaO	1·54	4·23	15·58
MgO	0·90	2·47	2·10
K_2O	1·14	2·42	2·85
Na_2O	0·12	0·18	0·15
Loss on ignition	3·04	7·40	20·70
Total	100·20	99·66	100·40

Alongside the grain degradation there occurs a consistent increase in the amount of clay grade separated ; it is the most striking series of increases of all the grades, and is sufficiently large to be readily detected by the elutriator without the refinements adopted in this investigation. Bearing in mind that only a slight increase occurs in the bond adsorption value, it follows that practically the whole of the mobile bonding material must have been acted upon in the raw sand ; consequently it would be expected to be removed in deflocculation without having to be rubbed off by the edge runner and disintegrator.

On the other hand this increase in the clay grade may have been produced by the mechanical reduction of sand to silt, and of silt to clay grade. The lower value of 1 per cent. clay grade in the prepared sand is evidence which strongly supports this latter theory.

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[1] This point is now under investigation in the Laboratory of the Birtley Iron Company,

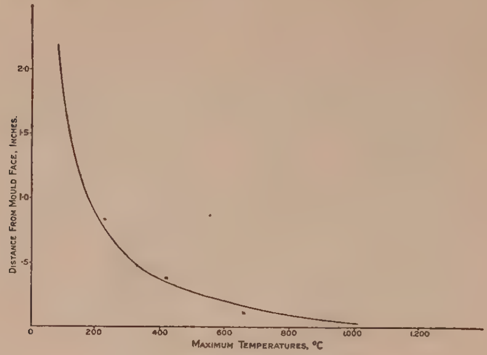

Fig. 6.

It seems very probable that both factors have contributed an indeterminate share and also that the considerable attrition has removed a portion of the static bond, which, being of little use as mobile bond and having a low bond value, would naturally lower the value per unit of clay grade after preparation. The

Table VI.—*Grade Chemical Analyses—Heck and South Cave Sands.*

Grade.	Raw S. Cave. Bulk Analysis.	Raw Heck. Bulk Analysis.	Mixture Medium Sand.	Mixture Fine Sand.	Mixture Clay Grade.
SiO_2	85·68 [1]	87·20	92·38	89·48	28·42
Fe_2O_3	5·68	1·75	0·56	1·60	9·80
Al_2O_3	4·30	5·23	3·36	4·58	13·78
CaO	0·24	0·20	trace	0·06	17·20
MgO	0·26	0·28	0·20	0·34	1·41
K_2O	0·48	3·04	1·85	1·73	4·62
Na_2O	0·18		0·21	0·28	0·24
TiO_2	0·15	N.D.	N.D.	N.D.	N.D.
Loss on ignition	2·48	1·45	1·08	1·30	24·00
Total	99·45	99·15	99·64	99·37	99·47

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[1] Professor Boswell, "Memoir on Refractory Sands," Part I., gives 0·36 per cent. P_2O_5 due to glauconite in this sand.

apparent increase in coarseness after casting is seen, on visual examination, to be due to the fritting of silt and clay around the sand grains and enlarging them. The loss of clay grade is a natural sequence of this. These aggregates are not broken down (although possibly to a small extent) by deflocculation; but treatment with hot hydrochloric acid causes separation in all but extreme cases taken from the mould faces.

TABLE VII.—*Grade Analyses—Silica Sand and Refractory Clay.*[1]

Grades.	Bulk Analysis. Silica Sand.	Clay.			
		Fine Sand.	Coarse Silt.	Fine Silt.	Clay Grade.
SiO_2	88·30	91·12	82·50	68·58	45·48
Fe_2O_3	1·74	0·22	0·62	1·74	1·24
CaO	2·66	0·16	0·52	1·84	8·86
Al_2O_3	1·48	5·44	9·44	15·78	22·32
MgO	0·96	0·11	0·36	0·71	1·35
K_2O	0·42	1·06	1·54	2·16	3·08
Na_2O	0·35	0·31	0·47	0·38	0·44
TiO_2	N.D.	N.D.	N.D.	N.D.	N.D.
Loss on ignition	4·64	1·32	2·68	6·90	15·40
Total	100·55	99·74	98·13	98·09	98·17

The acid-cleaned silica grains from the face of the mould were opaque after casting, apparently due to internal cracking; and the bond on the uncleaned sand was bleached to a light grey, fading off through half an inch of pinkish sand to the original colour. This bleaching seems to be more of a physical than a chemical (reduction of ferric oxide) change, as the yellow ferric ions were noticeable at once on pouring acid on the sand in a test-tube. On re-milling the used sand, a further portion of the fine silt and clay grades will be removed from the silica grains, and these, together with silt grade produced by the breaking down of the cracked grains referred to above, will gradually accumulate and yield a high content of silt-grade, such as is almost invariably found in floor sands which have seen much service.

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[1] The grade analyses refer to the clay only and not to the mixture of sand and clay.

[2] Owing to lack of time the titanium was not determined. Professor Boswell, "Memoir on Refractory Sands," p. 136, gives 1·85 per cent. TiO_2 in a bulk analysis of this seam of clay.

TABLE VIII.

	Raw.	Milled 2 Min.	Milled 5 Min.	Milled 10 Min.	And Disintegrated.	Distance from Mould Face.			
						0–½ Inch.	1 Inch.	2 Inches.	4 Inches.
Mechanical Tests—Mansfield Sand.									
Transverse . . .	92·5	145·5	167	162·5	170	120	158	173	163
Compression . .	580	634	850	895	870	470	610	700	870
Mechanical Tests—Heck and South Cave. 3 : 1 Mixture.									
Transverse . . .	89	N.D.	N.D.	375	420	78	250	238	355
Compression . .	375	N.D.	N.D.	1230	1280	360	700	750	1190
Mechanical Tests—Silica Sand and Clay. 5 : 1 Mixture.									
Transverse . . .	Nil	N.D.	N.D.	55	63	Nil	55	58	60
Compression . .	Nil	N.D.	N.D.	200	195	130	180	220	220
Mechanical Tests—Durham Sand.									
Transverse . . .	38	N.D.	N.D.	55	55	16	36	45	60
Compression . .	160	N.D.	N.D.	190	185	120	165	165	190

TABLE IX.—*Loss on Ignition per Cent.*

Sand.	Before Casting.	Distance from Mould Face after Casting.			
		0–½ Inch.	1 Inch.	2 Inches.	4 Inches.
Mansfield	4·82	3·25	4·78	4·83	4·85
Heck and South Cave . .	2·40	1·55	2·15	2·30	2·36
Sand and clay . . .	4·52	3·14	4·31	4·40	4·63
Durham	2·15	1·25	1·95	2·16	2·16

TABLE X.—*Bond Adsorption Values.*

(Milligrammes of Dye per 100 Grammes of Sand.)

Sand.	Raw.	Milled 2 Min.	Milled 5 Min.	Milled 10 Min.	And Disintegrated.	Distance from Mould Face after Casting.			
						0–½ Inch.	1 Inch.	2 Inches.	4 Inches.
Mansfield	1160	1200	1200	1240	1240	680	1240	1240	1220
Heck	540	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
South Cave	2860	"	"	"	"	"	"	"	"
Heck and South Cave	1220	"	"	1640	1800	680	1560	1735	1760
Silica sand	Nil	"	"	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Clay	3600	"	"	"	"	"	"	"	"
Sand and clay	700	"	"	640	700	240	620	660	700
Durham	320	"	"	360	340	110	260	320	320

TABLE XI.—*Values Shown per 1 per Cent. Clay Grade Separated in Elutriator.*

Sand	Mansfield.			Heck and South Cave.			Sand and Clay.			Durham.		
Treatment	Raw.	Prepared.	Cast.	Raw.	Prepared.	Cast.	Raw.	Prepared.	Cast.	Raw.	Prepared.	Cast.
Clay Grade	8·33	15·40	6·20	6·20	12·10	7·70	5·90	9·70	3·50	6·05	8·20	2·85
Transverse strength per 1 per cent. clay	11·20	11·05	19·40	15·10	34·50	10·10	...	6·50	...	6·30	6·71	5·60
Compressive strength per 1 per cent. clay	69·5	56·8	75·5	34·4	106·0	46·7	...	20·10	37·0	26·5	23·2	42·1
Bond adsorption per 1 per cent. clay	139·0	80·5	110·0	112·0	149·0	88·0	119·0	72·0	68·5	52·5	41·4	38·6
Loss on ignition per 1 per cent. clay	0·575	0·314	0·525	0·220	0·198	0·202	0·765	0·465	0·895	0·355	0·262	0·438

TABLE XII.—*Bond Distribution Factor.*

$$= \frac{\text{Strength of Transverse Bar} \times 100}{\text{Bond Adsorption Value}}.$$

Sand.	Raw.	Milled 2 Min.	Milled 5 Min.	Milled 10 Min.	And Disintegrated.
Mansfield	8·0	12·1	13·9	13·1	13·8
Heck and South Cave . .	7·3	N.D.	N.D.	22·8	23·3
Sand and clay . . .	Nil	,,	,,	8·6	9·0
Durham	11·9	,,	,,	15·3	15·2

There is a double disadvantage involved in the use of sand of high fine silt content: first, the porosity of the sand is seriously impaired, and secondly, the large surface displayed calls for a high clay content to cover it efficiently. The mixture of Heck and South Cave sands is the result of a successful attempt to imitate the good qualities of Mansfield sand in a coarser grain. In making up this mixture, South Cave sand was selected as having those properties which the writer has found to be essential in bonding materials for iron moulding sands in an unique degree, namely:

(*a*) A high content of fairly pure sand grade of considerable uniformity of grain size and possessing static bond.

(*b*) A low content of silt grade.

(*c*) A fairly high content of clay grade, exceedingly "fat," as shown by the dye adsorption value, of considerable permanence, as shown by the figures obtained from the "after cast" samples, and having a better chemical grade analysis than is really needed for this class of work (*vide* Mansfield clay grade).

(*d*) A high content of ferric oxide, which in the writer's opinion has a very great influence upon the skin of the castings produced.

The ideal diluent for South Cave must have a very high content of sand grade of similar grain size, must possess static in preference to mobile bond, and be low in silt and clay content. It should preferably contain ferric oxide in the static bond and must, of course, be of reasonably good analysis. In this matter Mansfield sand was rejected as being too fine in grain and carrying too much coarse silt, which, harmless in the fine-grained Mansfield, where microscopic measurement has shown the bulk of the grains to lie between 0·14 mm. diameter and 0·08 mm. diameter, would seriously impair the venting properties of a more open sand. Also the high bond carried is not needed.

Worksop sand was too fine in grain size, otherwise it would have been quite suitable. In Heck sand all the requirements are fulfilled.

TABLE XIII.—*Grade Analyses—Durham Sand.*

Grade.	Sand.	Silt.	Clay Grade.
SiO_2	94·20	80·35	50·20
Fe_2O_3	1·24	3·18	5·34
Al_2O_3	3·05	8·56	21·54
CaO	0·15	0·60	2·26
MgO	0·20	1·24	5·12
Alkalies	1·04	1·95	4·77
Loss on ignition	0·40	4·35	10·84
Total	100·28	100·23	100·07

Examination of the results shows that a large increase both in bond value and in mechanical strength occurs on milling and disintegration. When it is considered that the bulk of the bond is distributed, in a rather nodular state, over one-quarter of the sand, and that this has to be distributed over the remaining three-quarters, this increase is not surprising. The bond distribution factors tend to show, however, that the limit of useful milling has been reached.

The dye adsorption values show an increase which is much more considerable than had been expected; evidently deflocculation is not violent enough to reduce the strong clay nodules to a fine state of division.

Unit clay grade shows a higher value after milling, in comparison with that before, than in any of the other sands, and this lends support to the suggestion that useful mobile bond is progressively displayed as milling proceeds, to such an extent as to overcome the diluting effect of detrital matter resulting from degradation of sand and silt. The permanence of the bond is satisfactory, though not so good as in the Mansfield sand; it would seem to be affected by temperatures below 200° C. to a greater extent than the Mansfield bond, and this may be due to the South Cave bond being less ferruginous and more argillaceous than the bond in the Mansfield sand.

The values obtained in the tests on the silica sand and clay mixture are not of very great value; the clay was added dry and in size smaller than 10-mesh, tempering being effected during milling; pellets of clay were present even in the disintegrated sand, giving poorer tests than should have been obtained, and rendering accurate sampling impossible.

The fact that the raw mixture was too weak to give any mechanical tests also detracts from the value of the series. The detrimental effect upon bond distribution of the lack of static bond on the smooth grains of silica is accentuated by the modified success of the series of tests. The difficulty of coating smooth silica grains with clay is, however, well known; it is remarked upon by Dr. Moldenke in his "Principles of Ironfounding," and also in a paper read before the Institution of British Foundrymen, 1919–20.

Hanley[1] describes the successful mixing of new well-bonded sand, old sand, and a proportion of a poorly bonded local sand, together with a small quantity of fat refractory clay. The author has also succeeded in doing this, but only in such proportions that the grains with static bond predominate.

Finally, the Durham sand is an instance of great interest; almost the opposite of the Mansfield and Heck and South Cave sands. It is a sand which, on bulk chemical analysis, appears to be an excellent one, yet this promise is not borne out in practice. The author has used a considerable quantity of a Durham glacial sand of rather better composition than the sample here investigated; it vented badly, produced an indifferent skin on the castings, and lost its bond rapidly. The facts here demonstrated go far to explain this apparent contradiction between theory and practice; on examining the bond adsorption values it is evident that the sand is bonded with a rather lean clay which is not nearly so permanent as is that of the Bunter sands.

As regards the appearance of the castings produced from the test moulds, which were not blacked nor protected in any way, r.—PLATE I.

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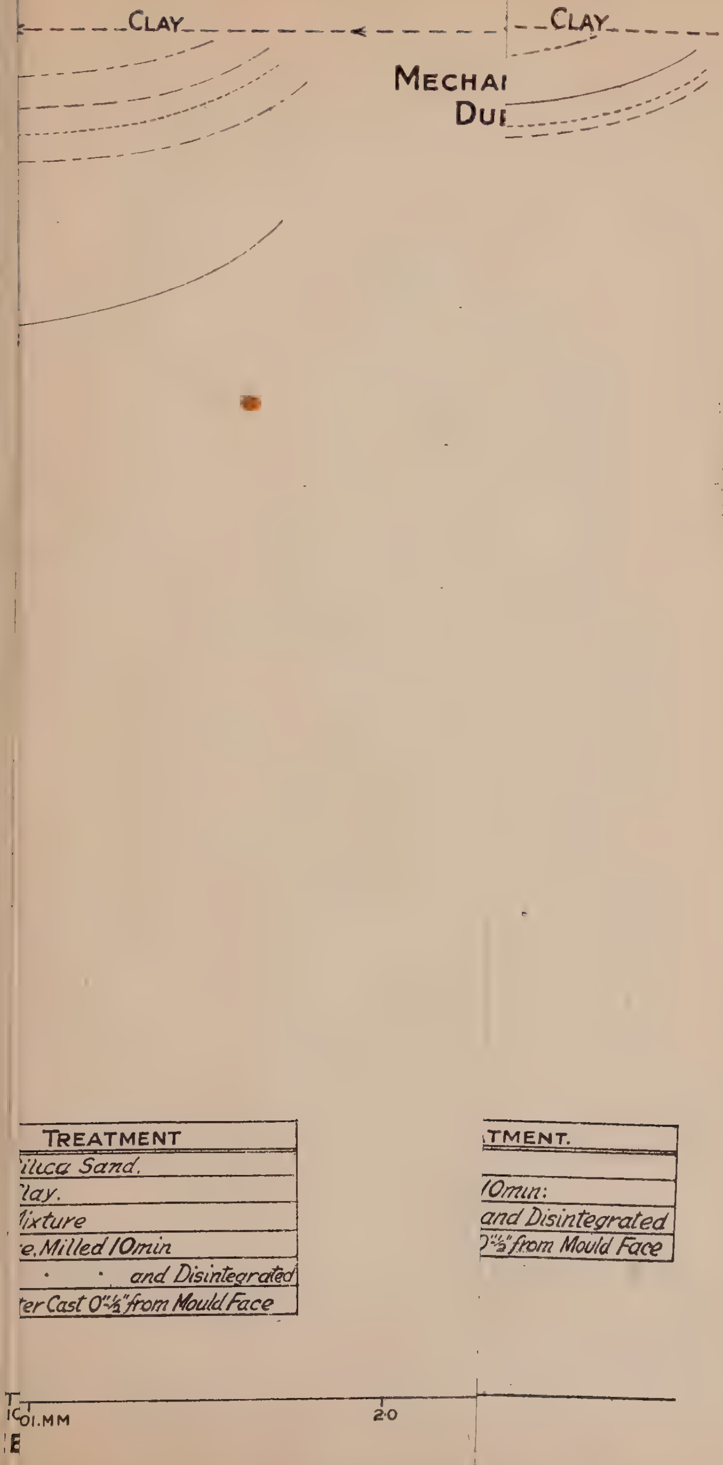
[1] *Transactions of the American Foundrymen's Association*, 1918, vol. 27, p. 529.



To face p. 80.

the casting from the Mansfield test had an excellent smooth blue skin which was only slightly better than that obtained with the Heck and South Cave mixture. The standard clay mixture came out with a loose scale of sand and minute pellets of burnt clay, which was rather reminiscent of a steel casting from a " compo " mould.

The Durham sand gave a greyish blue skin, rather rough owing to burning on.

Whilst the refractoriness of these sands is not one of the subjects under investigation, the author feels that it is not out of place to suggest that the ferric oxide content of moulding sands for grey-iron founding will one day, when the matter is fully investigated, be classed as a factor of prime importance. Although no evidence can be brought at the moment to support such a theory, it may be that in the presence of ferric oxide, a smooth blue skin of Fe_3O_4 is formed in preference to one of high FeO content, and consequently having a lesser tendency to form ferrous silicates with the sand grains. The curve showing the maximum temperatures to which the sands were subjected is a mean curve from the four casts, the results from which were practically identical. It will be noticed that the mean point for the aluminium wire lies outside the smooth curve ; this is due to its higher thermal conductivity. In the absence of a pyrometer, casting temperatures could not be determined, but would be in all cases approximately 1250° C.

PART VI.

CONCLUSIONS.

1. That the mechanical and physical properties of sands for grey-iron founding are of equal importance to the chemical analysis.

2. That the bond adsorption value obtained on the raw sand may be greatly modified by mechanical treatment.

3. That the most successful moulding sands contain both static and mobile bond.

4. That an appreciable degradation of the grains of a moulding sand occurs during the mechanical preparation as usually effected.

5. That the bond distribution factor is a characteristic of moulding sands that is of great importance in view of the excessive degradation which may be caused by prolonging milling beyond the time needed to effect the optimum distribution.

6. That no single test is sufficient on which to judge the practical value of many moulding sands, but a careful consideration of all those tests which have been described above.

The writer wishes to thank Mr. K. C. Appleyard, General Manager of The Birtley Iron Company, for having readily granted every possible facility for the conduct of this research. Also Mr. J. Brewis, Works Manager, for his ready assistance in many details.

DISCUSSION.

Mr. J. E. Fletcher (Dudley) said that, as representing more particularly the foundry side of the iron and steel industry, it was a pleasure to him to say how indebted that side was to Mr. Holmes's paper. In Great Britain there had been far too little investigation in connection with moulding sands, and the paper brought out just the kind of information which had been desired for some time by all foundrymen who wished to have a really scientific basis for their practice. He might say, as far as the Cast Iron Research Association was concerned, that their attention had been along those lines for some little time. They at once recognised the valuable work of Professor Boswell in initiating the proper investigation of moulding sands, and in Mr. Holmes they had almost the first of what he hoped would be a succession of investigators who would bring to them information of the character that they had in his paper. Mr. Holmes had shown them, to begin with, the great need there was to examine the mechanical characteristics of moulding sands, apart from mere consistency. Anyone who had done work on moulding sands would realise that in the old-fashioned tests they first of all separated out in a very elementary way a moulding sand by shaking it in water and allowing it to deposit. They were beginning to see that the effect of flotation was very important, and in the elutriation of the mechanical grades of the various sands described in the paper there was something to give them pause, as they considered the more or less colloidal behaviour of the fine and clayey portions of sands. The point that he wanted to direct attention to was the difficulty—a difficulty that founders wanted some light upon—in mixing sands. Mr. Holmes had shown them that sands could be milled for a very little time efficiently. Two or three minutes was sometimes sufficient to mill a sand so that it gave them all that they really needed for mixing purposes afterwards, but he had shown something in the paper which to his (Mr. Fletcher's) mind was infinitely more important, and that was, how careful they must be in mixing sands. It was not an easy thing to mix two sands and to get from them what was desired, either from the mechanical or from the chemical composition standpoint of the various grains. When once sand had been deposited under watery conditions and the wet sediment dried off, an attempt to mix those constituents would be found to present a very difficult proposition. That difficult proposition the founders had had before them—and in many cases the use of water in mixing was responsible for a great many of the moulder's troubles. It struck him that the results of the paper were going to be very important. They looked forward to Mr. Holmes, in the future, giving them still more information on the varieties of sands that interested moulders in various parts of the country, and it was along those lines that the British Cast Iron Association were trying to get together a schedule of sands and of standard tests. Mr. Holmes's paper had only started the work. They wanted to see something more, with respect to gas permeability, and the influence of liquid or metal erosion on sands, and also something more satisfactory respecting the actual bond adsorption values. The use of aniline dye was undoubtedly a qualitative sort of test, but to him it did not yet seem quite satisfactory, as in some cases the adsorption tests had not quite borne out the hopes that had been formed of them. With regard to the transverse test, he would ask Mr. Holmes whether he had tried the circular transverse test as against the square one, as obviously, from analogy with metal transverse bars, some difficulty might be anticipated from using a granular sort of test-bar in the way that was done in Fig. 1, with a rather sharp pointed application of the load. Tests had been made on the use of a circular test-bar, with not quite so radical a load impression as the one shown in Fig. 1. He did not see in the paper any mention of the overhanging or cantilever test of sands, which was very valuable, and might have been helpful in supporting the conclusions at which Mr. Holmes had arrived.

Dr. W. H. Hatfield (Sheffield) congratulated the author upon the paper. He fully agreed with his conclusions and endorsed every word that Mr. Fletcher had said. Moulding sands were a difficult proposition for investigation, as Mr. Holmes had no doubt found. While he had, quite rightly, in his paper, confined his attention to studying and recording the various physical and mechanical properties of the sands that he had been studying, what was of still greater interest both to the iron industry and to the steel industry was to devise simple, ready, and effective methods of determining the suitability of a given sand, either for steel castings or for iron castings. It seemed to him that after all the actual casting operation was an empirical test, in fact the only test which hitherto had been able to demonstrate satisfactorily for them the real merit of a sand. Some years ago, when on the Continent, he noticed in the Pas de Calais a foundry working on the sand actually dug up in the next field. That sand was simply carted into the works, milled (not too thoroughly milled, either) and then used as a green sand for casting excellent steel castings. It was perfectly efficient. He should consider that those various methods of investigating sands were incomplete until there was some quantitative forms of test which could say, without the casting operation, why such a sand as the one he was postulating was a most successful sand for steel casting. The paper marked the beginning of a quantitative study of sand, and showed the manner in which the question should be undertaken, and was an excellent piece of work.

With reference to the effect of coal dust when mixed in foundry sand a very interesting appearance was obtained. A bright "metallic" surface was given. It would be interesting to foundrymen if Mr. Holmes would give them any indication as to what he thought was the explanation of that surface.

Mr. E. ADAMSON (Sheffield) said the subject of sands was not one of which he had made a great study, but he congratulated the author on bringing the subject before the Institute in such a detailed and excellent manner. Sand was one of the next subjects which would have to be investigated in foundry practice, as there had been little research work published on the subject, and in his (Mr. Adamson's) opinion it was the next most important subject to pig iron. Mr. Holmes's paper was therefore an excellent instalment on so important a subject, and he hoped the author would do further work and publish it for the benefit of others who had not the opportunities available for conducting an exhaustive research.

Mr. ISAAC E. LESTER (Birmingham) said he was glad the subject of sand had been taken up at last. Moulding sand played so important a part in the engineering industry that it was about time it was investigated. As Mr. Fletcher, who was the acting director of the British Cast Iron Association, had said, that body wanted to get definite information, and it was beginning to see its way to do so. That was a start, and he hoped the work would be continued until sand could be standardised, although he much feared whether success would be attained in regard to that particular experiment to which Dr. Hatfield had referred, and to which he himself had often alluded—namely that the only good test of a casting was the serviceability of the casting. The same held good with regard to moulding sand—if a sand were good enough for a certain casting, it should be adhered to; if not, it should be discarded and another kind substituted.

Mr. H. K. SCOTT (London) considered the investigation useful. In the early days of the study of micro-metallography the good effect of much research was neutralised by observers working independently and without regard to previous investigation. He would ask the author if he was working on the same lines as those carrying out similar experimental work in the United States and elsewhere.

Many years passed before a standard test-bar for cast iron was agreed upon, and he wondered if the method of producing the sand test bar and its dimensions were agreed, or likely to be so, otherwise the results obtained might have little value in the future.

In iron founding the sand was not used alone, but mixed with various materials, such, for instance, as manure, in order to keep it open in texture. Would not that fact reduce the value of the investigation on pure sand. It was possible that a sand which gave the best results unmixed with other materials might be inferior to a supposedly second-rate sand when both were mixed with the materials used in practical work.

The author made no claim for the discovery, but his conclusion that the most successful moulding sands contained both static and mobile bond amply justified the work he had carried out. Mr. Scott supposed that the excellent Belgian sand referred to by Dr. Hatfield possessed both kinds of bond.

Mr. Holmes, in replying to the discussion, thanked Mr. Fletcher for his remarks. Mr. Fletcher had done a great deal of work himself on moulding sands, and had referred particularly to the difficulty of preparing sands. He quite agreed with him, and was inclined to think that in the next few years sand preparation would be revolutionised to a very large extent. The average foundry was very badly equipped as regards sand preparing machinery, and such machinery as was in operation had usually some vital defect. Mr. Fletcher found the bond adsorption test to be of limited value. So had he (Mr. Holmes). He had pointed that out in the paper. The test was useful for indicating how much bond there was, and for comparing consignments of sand from the same source, but he did not feel justified, with the amount of work he had done at present, in comparing really widely divergent sands by that method. It had to be borne in mind that the bond adsorption test simply showed how much bond there was. It might all be in one lump and all the clean sand might be in another part of the consignment; but it was only when it was distributed perfectly that the best use could be got out of the sand. As members would see from the tables, it was impossible to alter the bond adsorption value in some of the sands by preparation, by which more area would be exposed to the action of deflocculation. What he really wanted to bring out in his paper was that there were the two kinds of bond, fixed and moving, and that the latter could be displayed to poor or to good advantage. With regard to Mr. Fletcher's remark about the cantilever test, it was not smooth enough for weak moulding sands, but for a very strong material the cantilever test could, he thought, be used with some success. With weak sands there was almost always a slight jerk which was absolutely fatal. Dr. Hatfield had suggested that simple methods should be devised and they should be able to dispense with the existing tests. He agreed, but he was afraid it was a very long way off yet. There was a large field for work on the effect of various temperatures upon moulding sands. He had carried out a few investigations, but he had no definite results so far. In regard to the suggestion as to standardisation, so far as it has been possible, he had adopted the methods that had been used by American workers. The transverse bar, as he had taken it in his experiment, was that used by Hanley and Simonds, who were, he should say, two of the leading workers in America. He believed that the short bar was the standard bar at the present time. Mr. Scott brought out a point of great value (although it detracted to some extent from the value of the paper and of the work), when he referred to the addition of manure and other materials to sands. The sands referred to in the paper were all green sands, what was added to them in the works was coal dust, and from the work he had done he had found that coal dust reduced the mechanical strength of the sands. He had not done sufficient work on the matter at the present time to make it in any way worth publishing. The reduction of bond by coal dust and the possibility of getting a variety of coal dust that would be successful in use and would reduce the bond as little as possible, opened up a big field of its own. Detailed work on sand at the present time was so very wide, and so very little help was forthcoming in the meagre work which had been done before, that it was rather an appalling problem.

In regard to Dr. Hatfield's remarks on the effect of coal dust on the surface of a casting, if an article were cast in an open sand mould with a good deal of coal dust in it, the gas could be seen actually coming off just above the surface of the metal, and he was inclined to think that a cushion of hydrocarbons deposited carbon and enabled the metal to flow past the grains better. He thought it was simply a physical effect and a matter for a physical chemist to investigate. He did not think there was any actual chemical difference.

The need for standardisation was very great and should be taken up at an early date, not at home only, but internationally.

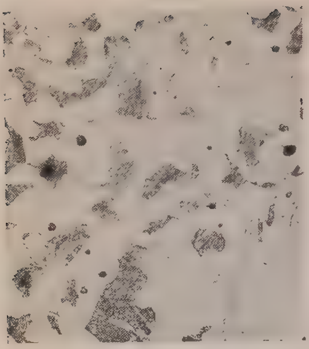


FIG. 2. Exp. 1. Hammered piece. Etched with picric acid. × 140.

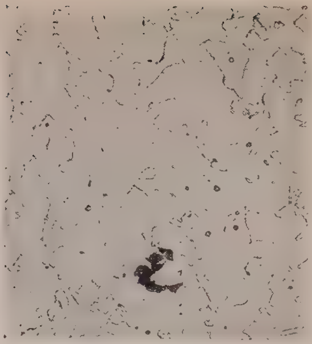


FIG. 3. Exp. 1. Unhammered piece. Etched with picric acid. × 140.

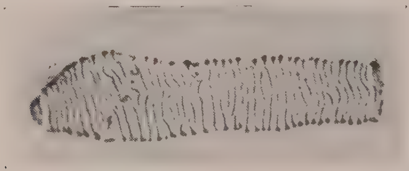


FIG. 4. Exp. 1. Typical pearlite in hammered piece. Sodium picrate stain. × 1050.

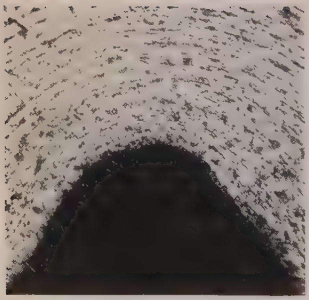


FIG. 5. Exp. 2. Pearlite at bend. Etched with picric acid. × 55.

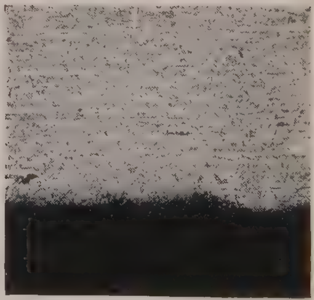


FIG. 6. Exp. 2. Hardenite in limb. Etched with picric acid. × 55.

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Iron and Steel Institute.

ON THE DIMINUTION OF LAG AT Ar1 THROUGH DEFORMATION.

By J. H. WHITELEY (Saltburn).

Evidence of lag in the crystallisation of pearlite, particularly in hypoeutectoid steels, is derived from several considerations. It is found in the well-known fact that, for a given steel, the temperature of the Ar1 transformation is not constant but is lowered as the rate of cooling is increased. Again, since the presence of carbide nuclei within the γ-iron areas induces crystallisation of the carbide and ferrite as globular pearlite at a temperature considerably higher than that at which growth takes place in the absence of such nuclei, lag must clearly occur in the latter case. Further, the growth of lamellar pearlite, when once started, does not occur simultaneously throughout the specimen. The change proceeds gradually and there is no difficulty in quenching a piece so that it contains areas of both pearlite and martensite intermixed. An example is seen in Fig. 3; the specimen showing this structure was cooled from 900° C. to 695° C., and held there for half an hour before it was quenched. Here, only one γ-iron area has changed to pearlite; if the specimen had been maintained at this temperature, or if it had been allowed to cool extremely slowly, the remaining γ-iron areas would have continued to crystallise almost one at a time. In Fig. 2 (Plate II.) the change has progressed much further but is still incomplete.

These facts make it clear that lag occurs at Ar1, which means that ordinary lamellar pearlite is formed from a supersaturated solid solution. In the case of supersaturated liquid solutions it has been found that agitation or stirring of the liquid is sometimes effective in initiating crystallisation and thus reducing lag.[1] Usually, in determining the recalescence points, the specimen is allowed to cool undisturbed, and it therefore appeared of interest, at any rate from a theoretical standpoint, to ascertain whether the temperature and rate of pearlitic growth could be increased through disturbances of structure caused by deformation of the steel when in the metastable condition of supersaturation. In the experiments described below, which were made for this purpose, two methods of deformation were used, namely, hammering and bending.

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[1] Recently, A. F. Hallimond, in discussing this question of delayed crystallisation, has remarked that for supersaturated solid solutions violent mechanical working may be the analogue of agitation (*Journal of the Iron and Steel Institute*, 1922, No. I. p. 359).

Description of Apparatus.—A small electrical furnace, A, Fig. 1, containing a silica tube 1 inch internal diameter, wound with nichrome wire, was placed vertically on a block of steel B, which rested upon two supports as shown. A bar of hard chromium steel C, ½ inch square section, was used as an anvil, and between it and the block B there was a thick pad of asbestos board. The thermocouple D passed through a hole drilled in the block, and was so placed that the temperature of the furnace at the surface of the anvil was recorded. A rod of manganese steel E was used to transmit the hammer-blows to the specimen on the anvil. This material was selected chiefly because it is non-magnetic; difficulty in manipulation during the experiment, owing to the magnetisation of the specimen, was thus avoided. The space around the anvil and thermocouple tube was well filled with asbestos fibre.

Experiment 1. *Deformation by Hammering.*—In this experiment the steel used was the same as that which had been employed in an investigation recently recorded on the formation of globular pearlite.[1] It consisted of a piece of ordinary mild steel plate which had been allowed to cool in the centre of a solidifying slag ball; the normal banded structure was thus eliminated and an approximate uniformity in composition obtained. The Ar1 point had previously been found, by quenching specimens, to lie between 685° and 690° C., and Ac1 between 715° and 720° C. Two small sections, differing in shape so as to be easily distinguished, each weighing about 1·0 gramme, were placed on the anvil C, and the rod E placed on the adjacent asbestos packing. The temperature was raised to 900° C. and then lowered in about ten minutes to 695° C. After the pieces had remained at this temperature for fifteen minutes, in order to give time for equilibrium conditions to be established, the rod E was carefully placed on one of them and a smart blow given with a hammer. To ensure against the effect of any slight difference in temperature between the end of the rod and the pieces, the rod was also placed on the other, but no blow was given. The positions of the two pieces were then interchanged, this being done by means of a thin rod of silica tube which had previously been placed in the furnace. During the next ten minutes the temperature was kept at 695° C. and the above procedure repeated, in varying order, about six times, and after a further five minutes the specimens were rapidly quenched in water. The deformation made by hammering in this way was found to be comparatively small; the same experiment was done several times, and in no instance was the depth of the piece ($\frac{3}{16}$ inch) reduced more than $\frac{1}{40}$ inch.

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[1] *Journal of the Iron and Steel Institute*, 1922, No. I. p. 339.

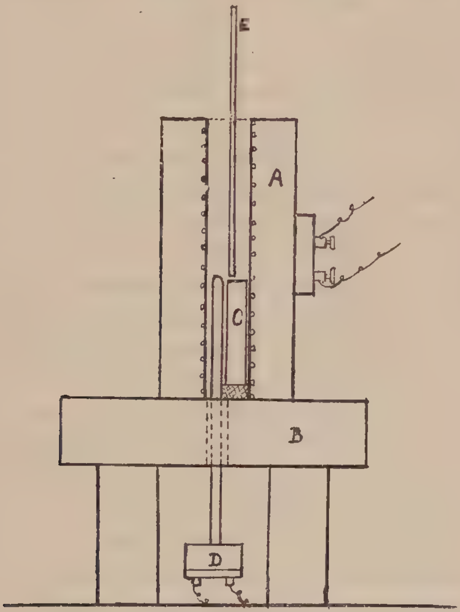

Fig. 1.

The results obtained from the repeated experiments all agreed. They showed unmistakably that lag at Ar1 could be diminished by slight deformation. Examples of the structures produced are given in Figs. 2 and 3 (Plate II.). Fig. 2 is that of the hammered piece; the dark areas are pearlite, and it is quite clear that the transformation was nearly complete when the piece was quenched. Very few unchanged areas of hardenite are to be seen. In Fig. 4 a typical pearlite crystal in this specimen is shown under a higher magnification; it will be noticed that the deformation has not been sufficient to cause any appreciable "divorce" to occur. Fig. 3 shows the structure of the unhammered piece in the same experiment. Here, only one area of solid solution has changed into pearlite. To have produced at 695° C. the same degree of transformation in this piece as in the hammered piece, a much longer heating would have been necessary. As before stated, the transformation at this temperature was found to take place very slowly in undisturbed specimens. In two instances the pearlite had not even begun to form in the unhammered piece, while in the hammered specimens the change was well on the way to completion. It would appear, therefore, that lag both as regards time and temperature can be diminished by deformation.

Experiment 2. *Deformation by Bending.*—The apparatus shown in Fig. 1 was also used in this experiment. In order to bend the specimens, a V-shaped notch, $\frac{1}{8}$ inch deep, was cut in the top of the anvil C, and the end of the rod E shaped like a chisel. A strip $\frac{1}{2}$ inch by $\frac{3}{16}$ inch of steel sheet, $\frac{1}{16}$ inch thick, of similar composition to the steel used previously, was placed across the notch, heated to 900° C. and cooled to 695° C. When the piece had remained at 695° C. for fifteen minutes, the rod was placed upon it so that the end was in line with the notch and two or three light blows were then given with a hammer. The strip was bent in this way through an angle of about 90°. After a further five minutes at 695° C., the piece was taken out and rapidly quenched. This experiment was also made repeatedly, in each case with the same result. At the bend, pearlite was always present, as shown in Fig. 5 (Plate II.), but in the limbs, where the metal had not been distorted, the structure consisted almost entirely of ferrite and martensite. An instance is seen in Fig. 6 (Plate II.). A similar, but less pronounced effect, was produced when strips were bent at 700° C.; pearlite was present only at the bends, about one-fourth of the austenite having crystallised.

The first results obtained by hammering only were therefore fully corroborated in these bend tests. They show that lag at Ar1 can be appreciably diminished through deformation.

It should be noted that although lag was reduced it was not completely eliminated by the methods of deformation used, for in a previous investigation with the same steel globular pearlite was found to grow between 705° and 708° C., when carbide nuclei were present in the austenite. Possibly, if the metal could be sufficiently distorted, lag in the formation of lamellar pearlite would be equally diminished.

In conclusion, it may also be mentioned that since a certain amount of lag also occurs at the Ar3 point, a few similar experiments were made in order to ascertain whether this supercooling could likewise be reduced by deformation. Strips were heated to 900° C., cooled to temperatures a little below Ac3, and then bent. Here, however, the separation of free ferrite from the solid solution did not appear to be accelerated by the deformation produced in this way.

Summary.—Evidence is given that when steel, in the metastable region at the Ar1 point, is worked, lag is markedly diminished.

DISCUSSION.

Dr. W. H. Hatfield (Sheffield) said that, as Mr. Whiteley stated in his summary, evidence was given that lag was markedly diminished by that mechanical disturbance. That was simply in conformity with analogous cases in physical chemistry. The eutectoid was to be looked upon as an uncooled liquid below a certain temperature, and it was reasonable to suppose that a mechanical disturbance such as that caused by the blow of a hammer would cause the eutectoid to split up into its constituents at a higher temperature than if it were not disturbed. Mr. Whiteley had described some very neat experiments, and he (Dr. Hatfield) would take that opportunity of saying that, along with others who were watching Mr. Whiteley's work, he felt he was contributing substantially to the knowledge of pearlite in its different aspects.

Mr. J. H. Whiteley, replying, said he was very pleased to know that Dr. Hatfield accepted the results which he had obtained. All the work he (Mr. Whiteley) had done so far in connection with pearlite formation, went to show that the principles laid down by Miers relating to crystallisation from supersaturated liquid solutions could also be applied to crystallisation from the solid solution. He would point out, further, that that being the case, no intermediate stages such as troostite and sorbite should occur in the transition from solid solution to pearlite, and, as a matter of fact, he had found ample evidence to show that those constituents did not form in that way.

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Iron and Steel Institute.

THE NITROGENISATION OF IRON AND STEEL BY SODIUM NITRATE.

By L. E. BENSON, B.Sc. (Manchester University).

During some experimental work specimens of armco iron and steels of varying composition were annealed in a salt-bath at a temperature of 500° C. for varying lengths of time. Subsequent microscopical examination showed that most of the specimens so treated had developed a structure within the ferrite grains similar to that generally associated with the presence of nitrogen.

The structure appeared to consist of a dark etching (picric acid or 1 per cent. alcoholic nitric acid) constituent, occurring as plates or lines usually along the cleavage planes of the ferrite grains, and occasionally along the grain boundaries. Photographs 1 and 2 (Plate III.) show this structure as it appears in armco iron and a plain 0·4 per cent. carbon steel. Careful examination of the original materials showed that in all cases the structure was perfectly normal. The original structure of the armco iron is shown in Photograph 3 (Plate III.).

The specimens were all normalised from 950° C. before annealing: The annealing was effected by immersing the specimens in a salt-bath composed of sodium nitrate (85 per cent.) and potassium chloride (15 per cent.) contained in a cast-iron crucible. The bath was maintained at the required temperature in a vertical nichrome-wound resistance furnace and the temperature controlled by a platinum platinum-rhodium thermocouple, also immersed in the salt.

Although the specimens whilst in the salt-bath stood on a porcelain plate, carburisation of the specimens by diffusion of carbon from the cast-iron container, or from carbonaceous impurity in the salt, appeared to afford a possible explanation of the structure, as at that temperature (500° C.) any carbide formed would precipitate along the cleavage planes and crystal boundaries. In order to explore this possibility a specimen of the normalised armco iron was annealed for two and a half hours at the same temperature in a bath of recrystallised sodium nitrate contained in a porcelain crucible. As a result of this treatment the iron was found to have developed the nitride structure to an average depth of 0·2 millimetre from the surface.

To obtain positive evidence of nitrogenisation both unannealed and annealed specimens of armco iron were analysed for nitrogen. The determinations were made colorimetrically, on 1 gramme of filings, by means of Nessler's reagent, after distillation from a strongly alkaline solution, as outlined by Whitehead in the appendix to Stromeyer's paper on Nitrogen and Steel.[1] By carefully standardising the conditions of the determinations very consistent results were obtained.

A sample of armco iron before annealing was found to contain less than 0·002 per cent. nitrogen. A specimen annealed for ten hours was observed under the microscope to exhibit the nitride structure to an average depth of 0·4 millimetre. Approximately 1·5 millimetre was filed off all the faces of this specimen and the filings collected. A further 1 millimetre was then filed off. The nitrogen content of the three samples was found to be as follows :

Outer layer	0·036 per cent. nitrogen
Intermediate layer	0·004 ,, ,,
Core	0·002 ,, ,,

From these determinations it would appear that the specimens in question had become nitrogenised through being annealed at a temperature of 500° C. in a salt-bath containing sodium nitrate.

Referring to the last-mentioned nitrogen determination, since the depth of metal filed off in the first instance and the depth of penetration of nitrogen are in the ratio of nearly four to one, it can be assumed that 0·036 per cent. is certainly much lower than the maximum concentration of nitrogen obtained : and since, according to Andrew,[2] 0·3 per cent. of nitrogen is sufficient to suppress the critical change points, there must have been a high enough concentration of nitrogen in the outer layers to exert a considerable influence on the physical and other properties of the material.

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[1] *Journal of the Iron and Steel Institute*, 1909, No. I.

[2] *Ibid.*, 1912, No. II.

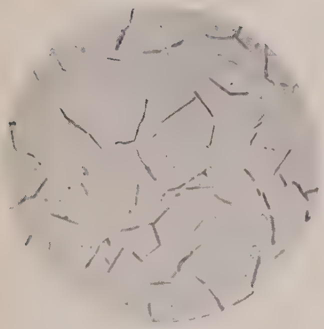

FIG. 1. Nitride Needles in Armco Iron. × 600.

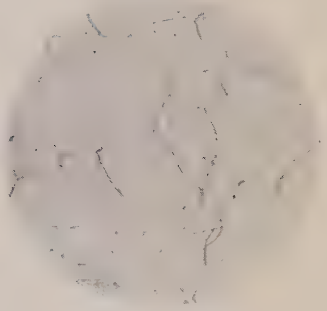

FIG. 3. Armco Iron before annealing. × 600.

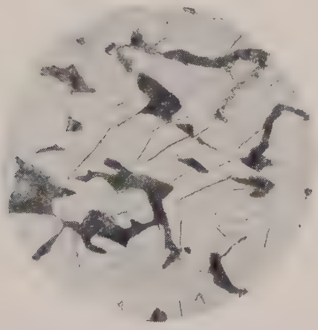

FIG. 2. Nitride Needles in Steel. × 400.

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RATE OF PENETRATION OF NITROGEN IN IRON AND SOME STEELS.

As sodium nitrate is frequently the chief constituent of salt-baths for low-temperature heat treatment, it was thought advisable to investigate how far nitrogenisation was likely to affect iron and steels under varying conditions. The influence of time on the rate of penetration of nitrogen in armco iron has been investigated up to eighty hours, and in various steels up to twenty hours.

The composition of the materials used in this investigation is given in Table I.

TABLE I.

Sample.	Mark.	Carbon per Cent.	Manganese per Cent.	Silicon per Cent.	Sulphur per Cent.	Phosphorus per Cent.
Armco iron . .	A	Guaranteed purity 99·84 per cent.				
Pure carbon crucible steels . .	B	0·16	0·12	0·05	0·03	0·025
	C	0·37				
	D	0·58				
Open-hearth steel .	E	0·41	0·54	0·12	0·07	0·04
Acid Bessemer steel .	G	0·40	0·89	<0·08	0·06	0·06

The procedure was to etch a cross-section of each specimen and examine microscopically on a Zeiss photomicrographic apparatus. The average depth to which nitrogen had penetrated in sufficient concentration to form nitride plates was marked on the ground glass screen and measured by substituting an engine divided scale $\left(\frac{1\text{ mm.}}{100}\right)$ in place of the specimen. In general, the penetration was observed to be very uniform, and only

TABLE II.—*Penetration of Nitrogen in Millimetres.*

Time of Annealing.	A.	B.	C.	D.	E.	G.
Normalised . .	0·00	0·00	0·00	0·00	0·00	0·00
1 hour . . .	0·15	0·00	0·05	0·00	0·00	0·00
5 hours . . .	0·30	0·20	0·20	0·15	0·15	very slight
10 ,, . . .	0·40	0·30	0·25	0·20	0·20	
20 ,, . . .	0·70	0·40	0·30	0·20	0·20	
80 ,, . . .	2·00	...	...	...	...	

in a very few cases was any difficulty experienced in arriving at a fair estimate of the average depth. The results of the penetration measurements will be found in Table II.

The results with regard to armco iron are plotted graphically in Fig. 1. Penetration of the nitrogen is comparatively rapid during the first few hours, but after fifteen to twenty hours the rate remains practically constant at 0·02 millimetre per hour.

The rate of penetration of nitrogen in steel in general appears to be considerably slower than in pure iron. In Fig. 2 the influence of time on the rate of penetration of nitrogen in the pure carbon steels is graphically represented, from which it is apparent that the rate of penetration of nitrogen in iron is seriously influenced by the presence of carbon, the rate being lowered as the carbon content rises.

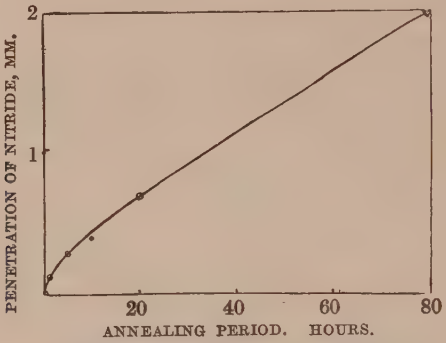

Fig. 1.—Penetration of Nitrogen in Armco Iron.

That the presence of pearlitic areas in the ferrite should impede the diffusion of nitride seems only natural, but the retardation produced by only 0·16 per cent. carbon as compared with that produced by 0·37 and 0·58 per cent. carbon seems sufficiently great to suggest that possibly influences other than merely the presence of pearlitic areas have contributed, and a greater solubility of carbide in alpha iron than has generally been supposed to exist might be expected to affect the rate of penetration thus.

Manganese would appear to exert a more profound influence on the rate of penetration than does carbon. Ample evidence of this fact is afforded by the time penetration curves for the three steels with varying manganese content (Fig. 3). This is in accordance with Tschischewski's observations on the nitrogenisation of iron manganese alloys.[1]

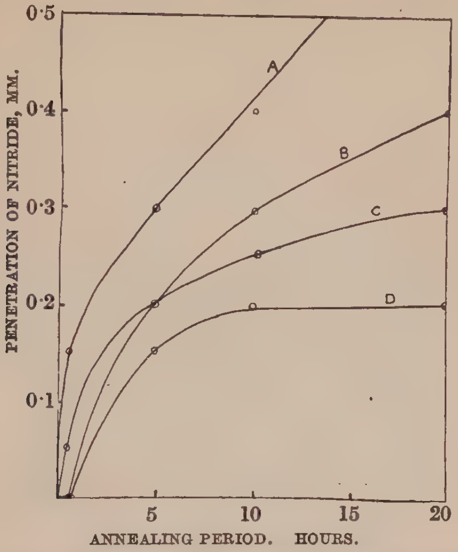

Fig. 2.—Penetration of Nitrogen in Pure Carbon Steels.

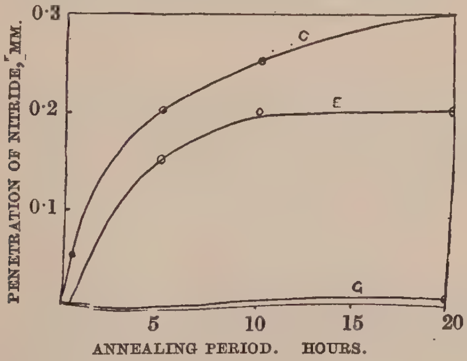

Fig. 3.—Penetration of Nitrogen in Steels containing Manganese.

The curve for the steel containing 0·4 per cent. carbon and 0·54 per cent. manganese is identical with that for the pure 0·6 per cent. carbon steel, but in the case of the acid Bessemer steel containing 0·89 per cent. manganese the penetration was very slight indeed. Even after twenty hours' annealing the nitride structure was only observable in the outermost layers.

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[1] *Journal of the Iron and Steel Institute*, 1915, No. II.

Dissociation of Iron Nitride.

Tschischewski has found that above 450° C. nitride of iron is unstable, and in this connection it is of interest that a piece of armco iron 0·5 centimetre thick, nitrogenised to such an extent that the characteristic needles could be observed almost to the centre of the mass, after heating in an open muffle for ninety minutes at approximately 700° C. showed no signs at all of nitride structure, and on analysis the nitrogen content was found to be only 0·0025 per cent.

Lines along which further investigation might be carried out suggest themselves, but the opportunity for this work has not so far arisen.

The work in connection with this paper was carried out with the assistance of a Simon-Carves Industrial Research Scholarship.

DISCUSSION.

Mr. J. H. Whiteley (Saltburn) said the paper reminded him of one given to the Faraday Society a year or two ago by Mr. J. A. Jones of Woolwich Arsenal on the influence of solutions of nitrates upon stressed steels. Mr. Jones showed that a solution of nitrates dissolved the grain boundaries more than the internal part of the crystal, and thus set up intercrystalline brittleness. Mr. Benson had brought forward no evidence to show that the inclusions seen in the photographs were really nitride of iron. They might, in fact, be substances containing nitrates in some form or other. It was very difficult to believe that nitrides would be formed in steel immersed in fused nitrates at the temperatures Mr. Benson employed. He (Mr. Whiteley) would suggest, therefore, that the crystals therein shown were not nitrides but nitrates, possibly basic nitrates, that had penetrated along the crystal boundaries, where in experiments by Mr. Jones the iron had been attacked more readily by the melt than at other parts. In the subsequent tests for nitrogen, those nitrates were probably reduced by nascent hydrogen when the sample was dissolved to form ammonia, or else, later, were reduced to ammonia by the ferrous hydrate in the alkaline solution. He believed it was the case that nitrates present in small amounts could give rise to the formation of ammonia in the nitrogen method. He would suggest to Mr. Benson, therefore, that before he proceeded further with that research he should endeavour to ascertain definitely whether the inclusions were really nitrides or nitrates.

Mr. E. H. Saniter, Member of Council, said that would be a very simple matter to ascertain, as the nitrates would probably be soluble in water and could be dissolved out. Mr. Benson probably polished his specimens with water when he prepared them for the microscope.

Mr. Whiteley said basic nitrates would not dissolve out.

Dr. W. H. Hatfield (Sheffield) said he was largely in sympathy with what Mr. Whiteley had said, and he would like to ask Mr. Benson if he could give them an equation which would account for the presence of the nitride of iron (sodium nitrate and iron).

Mr. E. Adamson (Sheffield) said he was under the impression that Dr. Thomas Baker, in reference to his research on the influence of silicon on iron, had analysed for nitrogen but had found it present only when his tube connections were leaking. When a sound connection to the tube was obtained no nitrogen was found, hence whenever nitrogen was suggested as being present in iron or steel he (Mr. Adamson) was in doubt whether it was actually present at all.

Mr. Benson, in reply, wrote that with regard to Mr. Whiteley's suggestion that the structure observed might be due to the formation of a nitrate, possibly a basic nitrate, he had no positive evidence that nitride was present in the iron after treatment. At the same time the structure in question appeared to be identical with that claimed by other workers to be due to nitride of iron, and in any case since salt baths were so frequently used for the heat treatment of steel the phenomenon was of sufficient interest to warrant bringing it to the notice of members of the Institute. In connection with the question of intercrystalline penetration the nitride lines occurred chiefly within the crystals, apparently along the cleavage planes and not usually at the crystal boundaries. The microstructure near the edge of the specimens did not suggest intercrystalline penetration.

He did not propose to advance any equation for the formation of iron nitride, as he had not formed any theory as to the nature of the reaction that took place.

Regarding Mr. Saniter's suggestion, the specimens were polished on a wet pad, hence it was improbable that the constituent in question was easily soluble in water. With reference to Mr. Adamson's remarks, the nitrogen estimations were very carefully carried out and he believed that they were reliable.

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Iron and Steel Institute.

SOME EXPERIMENTS ON THE FLOW OF STEELS AT A LOW RED HEAT, WITH A NOTE ON THE SCALING OF HEATED STEELS.

By J. H. S. DICKENSON, F.Inst.P., M.I.A.E. (Sheffield).

PART I.

The Flow of Steels at a Low Red Heat.

I. Introductory.

Recent developments in chemical engineering, particularly the growing importance of synthetic ammonia production, have called for the provision of metallic containers capable of withstanding considerable stress at elevated temperatures, and for long periods. Investigation of the mechanical properties of steels and alloys in the heated state has therefore become a matter of very direct practical consequence, and has, for some time past, received much attention in the Research Laboratories of Messrs. Vickers, Ltd., chiefly in relation to definitely stated conditions of service. As some of the results of this work appear to be of general interest, they are communicated to the Institute in the present Note. Although the general literature on the mechanical properties of iron and steel at high temperatures is decidedly less scanty than is sometimes stated, very little has been published regarding the behaviour of typical alloy steels when subjected to stress at a low red heat, and upwards. A Note by Guillet on a nickel-chromium-tungsten alloy,[1] one or two confidential leaflets issued during the war by the Air Ministry on the strength and scaling of aero-engine valve steels at high temperatures,[2] a recently issued Technologic Paper of the U.S. Bureau of

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[1] L. Guillet, "Alliages ayant des propriétés remarquables à températures très élevées ou à températures très basses," *Revue de Métallurgie*, 1914, p. 969.

[2] C. F. Jenkin, "Report on Materials of Construction used in Aircraft," H.M. Stationery Office. 1920.

Standards,[1] and a few trade pamphlets issued by manufacturers, embody most of the published data available.

These almost invariably consist of graphs in which tensile test results, "tensile strength," reduction of area, elongation per cent., and so on, are plotted against the temperature at which the test was made, great care being taken to eliminate the disturbing factor of time by carrying out each test under as nearly the same conditions of heating and loading as possible, the duration of each test being usually relatively short, at most a few hours, with an actual loading time of a few minutes. A series of curves obtained in this way are given in Fig. 1. It cannot fairly be claimed that such information gives more than a general indication of the relative ability of different materials to meet the working conditions usually encountered by the exhaust valve of an aero-engine, or the retorts, catalyst tubes, and so on, of the chemical engineer.

It certainly does not enable a designer to construct a container which can confidently be depended upon to maintain shape indefinitely at some high temperature, above a low red heat, when in a state of stress. This is, after all, the practical requirement; that the container, or valve, or whatever else it is, shall not suffer so much deformation that failure takes place, or renewal is necessary, in less time than is economically permissible.

In actual fact all the steels which the author has investigated behave very much like highly viscous fluids at temperatures well below the critical range, and cannot be said to have any definite strength at a red heat. Thus statements, actually made, in more or less official reports, to the effect that—

(*a*) A high-speed steel has a tensile strength of 20·1 tons per square inch at 650° C., or that

(*b*) A 0·38 per cent. carbon steel has a tensile strength of 39,950 lbs. per square inch at 550° C.,

are not only meaningless, but may be misleading. Either steel would stretch continuously, and finally break, under much less load, if given time. It will be shown, towards the end of this paper, how very far from the truth the above figures actually are.

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[1] H. J. French, Technologic Paper No. 235, "Tensile Properties of some Structural Alloy Steels at High Temperatures."

It follows that the property of principal importance to the engineer who wishes to subject highly heated steel to stress is the equivalent of the viscosity of a fluid.

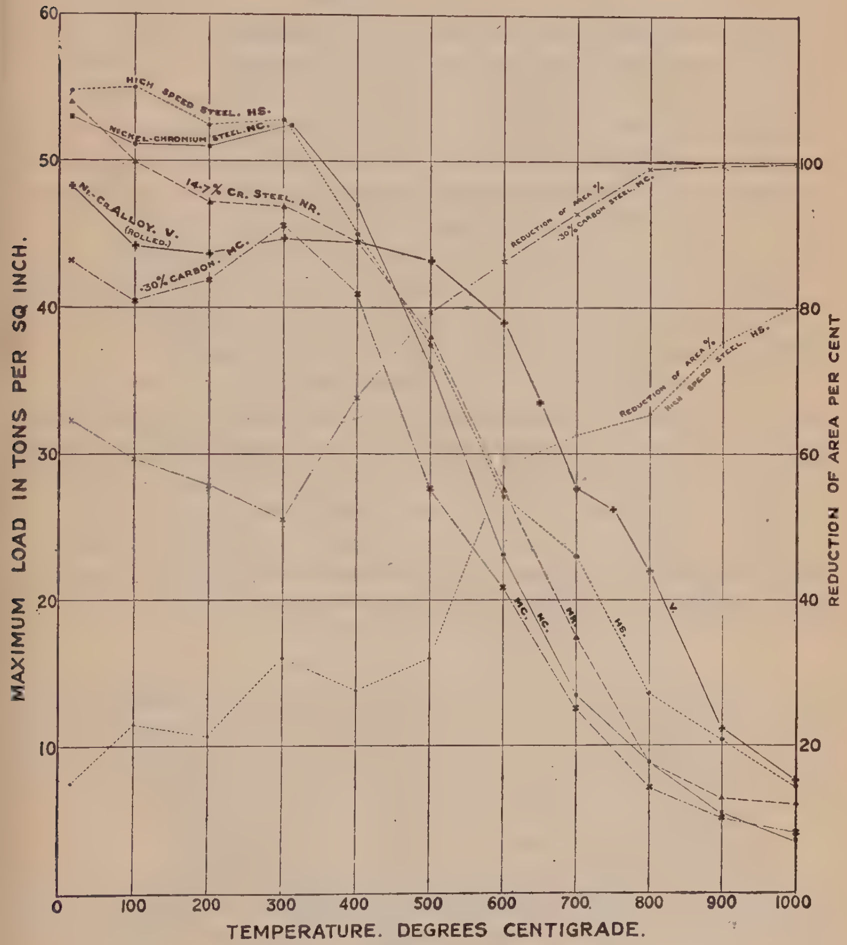

Fig. 1.

For the solution of a problem of immediate practical importance the author was content to ascertain, for each of a selection of steels, that temperature at which the rate of flow does not exceed a very small, and practically negligible amount, under a uniform stress of 8·5 tons per square inch, these experiments being described in the following sections.

It should be observed that the influence of the rate of straining, on the stress required to produce fracture of very soft steel at high temperatures, was examined by Rosenhain and Humfrey in 1913,[1] and was referred to by Rogers in discussion,[2] so that the author would have hesitated to raise the matter again had not the necessity for this been, unfortunately, so apparent.

The selection of material for highly heated and stressed containers, &c., is dependent upon a further factor, the resistance of the heated metal to the attack of hot gases or chemical substances. It is proposed to deal, in Part II., with the varying resistance of a series of steels to oxidation by air and furnace gases. Cases do, however, arise when the possible bad effect of hydrogen, ammonia, and other gases has to be considered.

Before proceeding, the author would point out that the several series of experiments dealt with in the following sections were commenced at different times, and in connection with distinct inquiries, so that although a similar selection of typical steels has been made in each case, the corresponding samples of two different series are not always from the same cast. It is considered that this will not affect the usefulness or validity of certain comparisons made in the conclusions.

II. THE BEHAVIOUR OF A SERIES OF TYPICAL STEELS WHEN SUBJECTED TO RAPIDLY APPLIED TENSILE LOADING AT TEMPERATURES RANGING BETWEEN 15° C. AND 1000° C.

1. The test-pieces were machined from rolled bars. The analyses and heat treatment are shown in Table I.

2. The tensile test-pieces were machined to give a parallel length of 4 inches by 0·564 inch diameter, the nichrome-wound silica heating tube having a length of 6¼ inches. They were shackled in an ordinary 50-ton Buckton single lever machine and steadily heated. The heating period varied a little between twenty minutes and thirty minutes, but on arriving at the desired tem-

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[1] Rosenhain and Humfrey, "Tenacity, &c., of Soft Steel at High Temperatures," *Journal of the Iron and Steel Institute*, 1913, No. I. p. 244.

[2] *Ibid.*, p. 294.

TABLE I.

Symbol.	Class of Steel.	Dia. of Bar.	Heat-Treatment.	Analysis.								
				C.	Si.	Mn.	S.	P.	Ni.	Cr.	W.	V.
		Inch.	°C. °C.									
MC	0·30 per cent. carbon steel	$\frac{7}{8}$	Oil-hardened 850, tempered 575	0·30	0·12	0·54	0·027	0·038	0·51	0·14	...	...
HTC	0·45 per cent. carbon steel	$1\frac{1}{8}$	Water ,, 870 ,, 600	0·45	0·37	0·79	0·022	0·024	nil	0·02	...	...
NC	Nickel - chrome steel	$\frac{7}{8}$	Oil-hardened 830 ,, 600	0·25	0·11	0·36	0·031	0·026	3·63	0·55	...	
NR	High - chromium steel	$\frac{7}{8}$	,, 925 ,, 650	0·26	0·59	0·17	0·066	0·016	0·39	14·68	...	
HS	High - speed steel	$\frac{7}{8}$	Annealed 800 ...	0·62	0·39	0·16	0·053	0·021	0·16	3·98	17·36	0·66

perature each piece was carefully maintained at that temperature for ten minutes. It was then broken exactly in the usual way, so that the total period of loading occupied only about one to two minutes. At first, efforts were made to observe a yield point by the fall of the beam, but the results obtained were very erratic, and are not here given. In view of the shortness of the heating period, and the relatively large size of the test-pieces, no effort was made to avoid oxidation at the higher temperatures, while the entirely arbitrary character of the test made it appear unnecessary to seek uniformity of temperature along the entire gauge length, by specially arranged winding, to compensate for the end cooling, as described by Bengough.[1] For the purpose of such comparisons as are provided by the present series of tests, it is probable that the ductility would be satisfactorily indicated by the elongation per cent. on the middle 2 inches, in spite of a fall of temperature from the middle of the gauge length outwards; but in any case the reduction of area, which is perhaps the better ductility index, is used in comparing these results with those of the series of prolonged tensile tests described in Section II.

3. The test results are set out in Table II., the maximum load results of each steel, except those of the 0·45 carbon steel, being plotted in the diagram, Fig. 1, against the temperature. This diagram also shows two characteristic reduction of area curves, those of the 0·30 per cent. carbon and high-speed steels, as well as the maximum load results obtained from a rolled bar of nickel chromium alloy, containing 65 per cent. Ni and 12 per cent. Cr.

Beyond observing that these results compare fairly well with most of the published determinations of "tensile strength" at high temperatures, it is not proposed to discuss them in this section, but to consider them at a later stage, along with those of the prolonged tensile tests dealt with in the next section.

III. Prolonged Tensile Tests at Constant Load and Temperature.

1. The experimental work dealt with in this section was commenced in the Vickers Research Laboratory in connection with the manufacture of a number of large catalyst tubes for a

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[1] *Journal of the Institute of Metals*, 1921, No. 2, p. 433.

TABLE II.

Temperature at Time of Loading.	Class of Steel.									
	MC. 0·30 per Cent. Carbon.		HTC. 0·45 per Cent. Carbon.		NC. Nickel-Chromium.		NR. High-Chromium.		HS. High-Speed.	
	M. S. Tons per Sq. In.	R. of A. Per Cent.	M. S. Tons per Sq. In.	R. of A. Per Cent.	M. S. Tons per Sq. In.	R. of A. Per Cent.	M. S. Tons per Sq. In.	R. of A. Per Cent.	M. S. Tons per Sq. In.	R. of A. Per Cent.
Room temperature	43·2	64·8	51·1	64·8	52·8[1]	66·8	54·0	57·0	54·7	15·0
100° C.	40·4	59·2	47·0	59·2	51·2	64·8	49·9	54·6	55·0	23·0
200° C.	41·8[1]	55·8	47·6[1]	60·4	51·0[1]	62·6	47·2	58·1	52·4	21·4
300° C.	45·6[1]	51·0	49·2[1]	53·4	[2] 52·4[1]	55·2	46·8	57·0	52·8[1]	32·0
400° C.	40·8	67·8	46·8	69·8	47·0	68·8	44·4	52·2	45·0	27·6
500° C.	27·6	79·4	33·2	83·4	36·0	82·7	38·0	64·4	37·4	32·0
600° C.	20·8	86·1	24·4	84·1	23·2	88·6	27·6	70·7	27·1	58·1
640° C.	...	...	18·5	90·9	...	...	...	...	...	...
700° C.	12·6	92·8	10·4	92·0	13·4	88·6	17·4	84·1	23·0	62·6
800° C.	7·2	99·0	8·2[3]	93·4	8·8	96·2	8·8	93·4	13·6	65·4
900° C.	5·1	99·6	4·4	95·2	5·4	95·4	6·4[1]	91·4	10·4[1]	75·3
1000° C.	4·0	99·8	3·4	98·8	3·6	99·9	6·1	91·4	7·2	80·3

[1] Broke outside middle 2 inches length.

[2] Actually 310° C.

[3] Actually 786° C.

synthetic ammonia process. These tubes were to be maintained at a temperature of about 600° C., under an enormous internal pressure, a long mean life of tube under these very severe conditions being essential to the economic success of the process.

After consideration it was decided to make them of a nickel-chromium alloy, known to possess high resistance both to oxidation and deformation when under stress at high temperatures, but meanwhile to carry out some laboratory trials to ascertain the precise behaviour of the alloy when maintained for considerable periods under the conditions of stress and temperature existing at the bore of the tube in operation. These prolonged tensile tests gave satisfactory indications, since confirmed by the good behaviour of the tubes in service; but had the matter rested there the results would hardly have interested the members of this Institute. Subsequently, however, it was considered useful to carry out similar tests with a selection of typical steels.

2. *Programme.*—In the first instance one test-piece from each of the selection of typical steels, of which details are given in Table III., was to be kept in tension under a constant dead load of 8½ tons per square inch, and at a temperature maintained as uniformly as possible at 625° C., until breakdown occurred, or until it appeared unnecessary to continue.

Subsequently at least two further tests were to be made on each steel, under exactly the same load, but at temperatures to be determined on the results of the 625° C. test, the rate of extension being determined by overall measurements at suitable time intervals in all cases.

Finally, a tensile test-piece from each steel was to be placed under the same dead load of 8½ tons per square inch, and heated at the uniform rate of 50° C. per thirty minutes, until fracture occurred, the overall extension being measured at short regular intervals.

3. *Selection and Treatment of Test Samples.*—The first five samples set out in Table III. were rolled bars, taken directly from the steel warehouse stock, the nickel-chromium alloy samples being cut from a cast 6-inch square crucible ingot.

The question of heat-treatment presented some little difficulty, but eventually it was decided to put the five steels in a tough condition by the treatment shown in Table III., and leave the

TABLE III.

Symbol.	Class of Steel.	Diam. of Bar.	Heat-Treatment before Machining Test-Piece.				Analysis.								
							C.	Si.	Mn.	S.	P.	Ni.	Cr.	W.	V.
		Inch.		°C.		°C.									
MC	0·30 per cent. carbon steel	$\frac{7}{8}$	Oil-hardened	850,	tempered	575	0·30	0·12	0·54	0·027	0·038	0·51	0·14	...	...
HTC	0·45 per cent. carbon steel	1	,, ,,	850	,,	600	0·45	0·37	0·79	0·022	0·024	...	0·02	...	...
NC	Nickel-chromium steel	$\frac{3}{4}$	,, ,,	830	,,	600	0·25	0·11	0·36	0·031	0·026	3·63	0·55	...	...
NR	High chromium steel	$\frac{7}{8}$	,, ,,	925	,,	650	0·26	0·59	0·17	0·066	0·016	0·39	14·68	...	...
VA	High speed steel	$\frac{13}{16}$	Annealed	800		...	0·60	0·28	0·23	0·044	0·029	...	3·49	14·09	0·72
CT	Nickel-chromium alloy. Cast	...	...	...		...	0·54	0·73	0·10	0·032	0·030	69·90	15·50	...	...

alloy untreated. With such a series the effect of "normalising" is to produce anything but similarity of initial condition.

It should be observed that four of these steels are of the same casts as the corresponding samples used in Section II., but that the high-speed steel and nickel-chromium alloy samples are of different origin.

4. *Apparatus.*—The apparatus provided for six tensile tests to be carried out simultaneously, as illustrated by Fig. 2, Plate IV., Fig. 3 giving the principal details of one unit, and of the test-piece.

The extreme urgency of the initial experiment made it impossible to wait for the refinement of knife-edges, but the pins were very accurately fitted. A measurement of the load applied by each lever, readily made by compressing copper crusher gauges in a suitable device, showed that each lever exerted practically the same pull of between 21 and 22 cwts., the calculated load being 21 cwts. The load on the test-piece may be safely taken as 8·5 tons per square inch in all cases.

The 8 in. × 0·125 sq. in. gauge length of each test-piece was punch-marked along one side in 1-inch lengths, for measurement after fracture, the thermocouple hot junction being held at the middle mark by a small wad of asbestos bound tightly in position by a few turns of platinum wire. This not only prevented movement of the couple during subsequent fitting of the heating tube, but ensured that the couple was actually at the temperature of the test-piece.

The gauge length was additionally provided with two punch-marks, 180 millimetres apart, and external to the heating furnace, for the purpose of making periodical overall measurements during the progress of the test.

The electric furnaces were wired in parallel, each having a small external adjustable resistance, while the nichrome winding of the silica heating tube was 110 inches long, in about forty-five evenly spaced spiral turns, no effort being made by closer winding towards the ends to compensate for end chilling.

Trial showed that the temperature in the middle 2 inches of the gauge length was not quite uniform, the central point being higher by about 20° C. than the points 1 inch away on either side. The variation in the middle inch was not more than 10° C., but it was deliberately intended that breakdown should occur at the central point, and therefore a little higher temperature was desired.

The annular space between heating tube and test-piece was stopped at both ends by a filling of asbestos fibre and clay, this being constantly repaired when loosened by extension of the test-piece, but no other effort was made to prevent surface oxidation or scaling, which never became excessive, even during the longer runs, since the temperatures were never very high for long periods, except in the case of the relatively non-scaling nickel-chromium alloy.

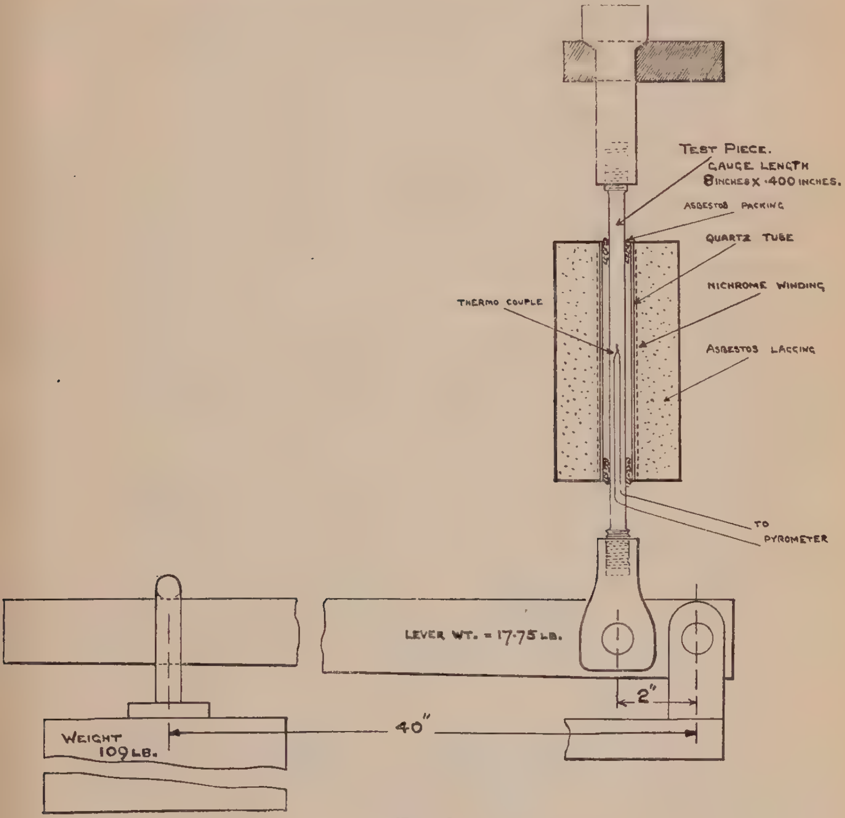
TEST PIECE.
GAUGE LENGTH 8 INCHES X ·400 INCHES.
ASBESTOS PACKING
QUARTZ TUBE
NICHROME WINDING
THERMO COUPLE
ASBESTOS LACING
TO PYROMETER
LEVER WT. = 17·75 LB.
2″
40″
WEIGHT 109 LB.

FIG. 3.

Finally, the temperatures were recorded by a Cambridge thread recorder, the couples being carefully checked before and after use. No checking was possible during the course of a test, which in one case continued for 6041 hours, but no appreciable change was found in any instance.

The long duration of some of these trials made a robust and reliable pyrometer far more suitable than a very sensitive instrument, liable to go wrong, and to require frequent checking.

5. *Testing Procedure.*

(a) *Duration Tests at Constant Load and Temperature.*—Great care was necessarily taken in applying the load, the weight being supported while the test-piece was screwed into position, and afterwards most carefully lowered, so that no " live-load " was momentarily produced.

The temperature was then steadily raised to the desired height, where it was maintained day and night, and sometimes for months, until fracture occurred, or it was deemed unnecessary to continue, a daily measurement being made of the distance between the two external (180 millimetres) gauge marks.

Naturally more frequent observations were made when called for by rapid extension of the more highly heated test-pieces, or when rupture became imminent at the end of the longer runs.

Owing to current fluctuations, principally those due to meal-time stoppage of machines, it would have been quite impossible to keep the temperature absolutely constant, within, say, 5° C., without unremitting attention and continuous rheostat adjustment.

This was considered both impracticable and unnecessary, but it was found quite possible to keep within a range of 50° C. for long periods, with little or no alteration of the external resistances, and it was therefore decided to run a series of test-pieces from each steel in 50° C. ranges, as 550° to 600° C., 600° to 650° C., and so on. It is utterly impossible to embody the pyrometric records in this paper, over 300 linear feet of double recorder sheet having been used; but it may be understood that where the temperature range for any given specimen is stated as, say, 600° C. to 650° C., the mean temperature was not far from 625° C., especially in the longer runs.

In the shorter tests, of less than 100 hours' duration, it was not always possible to compensate for a long spell towards the low limit of the range, during a week-end for example, by a corresponding period towards the upper limit.

(b) *Tests at Constant Load and Uniform Rate of Heating.*—After the test-piece was placed in position and the load applied, the 180-millimetre gauge length was measured. The temperature was then slowly raised, by means of a specially devised rheostat, at the uniform rate of 100° C. in every sixty minutes, an overall measurement being made at 100° C., and thereafter on reaching each additional 50° C., great care being taken to make this coincide with half-hourly periods.

Later, as the rate of extension increased, more frequent measurements were made, usually at each rise of 10° C., in six-minute periods. Finally, the temperature at which the test-piece ruptured was carefully noted. It should be added that all these test-pieces were pulled by the same lever.

(c) *Measurement and Micro-Examination of Broken Test-Pieces.*—After fracture of a test-piece the extension on each (original) 1-inch length was determined, but as almost the whole stretch invariably occurred within the middle 2 inches, only the elongation per cent. on this portion of the gauge length is here recorded. The reduction of area at the fracture was always taken, and, in a number of selected cases, a longitudinal half-section was removed to include the fracture, and microscopically examined.

6. *Discussion of Test Results.*—Table IV. sets out the principal results obtained from every test-piece of the two series :

(*a*) Constant load and constant temperature, and

(*b*) Constant load and uniformly rising temperature.

It also includes figures, extracted from the smoothed curves of Fig. 1, to show the temperature at which the four steels, MC, HTC, NC, and NR, would rupture under a load of 8·5 tons per square inch, *under the loading conditions described in Section II.* In these cases the duration at full load, of 8·5 tons per square inch, and at the temperature stated, is estimated at six seconds. In actual fact it would not matter very much, as regards the purpose for which this figure is to be used, whether the duration was taken as thirty seconds or 0·30 seconds, but the period in the tensile tests described on p. 109, between the moment of attaining maximum load and the fracture of the specimen, is certainly well within this range, and probably quite near the six seconds stated in Table IV. It is necessary also to state, in the same table, the period during which the test-piece of the series (*b*), constant load and rising temperature, were at the temperature of breakdown. Here a close approximation is possible, the figure given being three minutes ; the time occupied in rising the 10° C. prior to final collapse of the test-piece ; and this duration is not treated as a mere estimate in Table IV. The only remaining estimates in Table IV. are those of the probable lives of test-pieces subjected to constant load and temperature for long periods, and eventually withdrawn, stretched, but unbroken. A number of such cases are shown in Figs. 5 to 9, which, each confined to a single steel, show the rate of extension of every test-piece, the plotted results being the actual daily measurements of overall length.

The extension-temperature diagrams of the (*b*) series are plotted in Fig. 4, and show that up to 400° C. all the steels extend alike, the upwards curvature being probably due to a falling nodulus of elasticity. Thereafter the curves diverge, a considerable amount of flow taking place, in each case, at temperatures well below that finally reached. An interesting departure from the general form of the curves is that of the high-speed steel, but the author has been unable to check this result, which was obtained from the last remaining test-piece of steel VA.

It scarcely requires mention that the diagrams of the (*a*) series, Figs. 5 to 9, not only represent a very considerable amount of labour, but present some very remarkable results. Thus the case of a test-piece of nickel-chromium alloy (Vikro) which extended continuously from the first day of loading (at 625° C.), but only broke after 6041 hours, and the almost equally surprising extension curve of the 14·7 per cent. chromium steel, which stretched continuously for 1728 hours before final breakdown, are results little expected by the author at the outset of this work. However, these extension curves will be discussed later.

Returning now to the "withdrawn" test-pieces of these diagrams, an estimate of the probable time before rupture would have occurred, had the test proceeded, was obtained in each case by comparing the time required to produce the same extension in unbroken and broken (because more highly heated) specimens of the same steel, the assumption being made that the complete

TABLE IV.

1. Type of Steel.	2. Test-Piece No.	3. Temperature Range.	4. Duration of Test in Hours before Fracture or Withdrawal.		5. Time at Load of 8·5 Tons per Sq. In., and Temperature as stated in Col. 3.	6. Elongation on Middle 2 Inches. PerCent.	7. R.A. PerCent.
			Hours.				
0·30 per cent. carbon	MC1	500°/550°	1739.	Withdrawn	3,400 hrs.[1]	...	...
	MC2	550°/600°	956.	Broken	956 ,,	30·0	85
	MC3	600°/650°	28.	,,	28 ,,	29·0	88
	MC4	700° C.		...	3 mins.	32·5	92
	MC	775° C.		...	6 secs.[1]	...	...
0·45 per cent. carbon	HTC7	500°/550°	1405.	Withdrawn	2,600 hrs.[1]	...	...
	HTC5	550°/600°	195.	Broken	195 ,,	32·0	84
	HTC4	600°/650°	26	,,	26 ,,	32·0	84
	HTC8	680° C.		...	3 mins.	33·0	90
	HTC	775° C.		...	6 secs.[1]	...	...
Nickel-chromium	NC2	500°/550°	701.	Broken	701 hrs.	40·0	85
	NC1	550°/600°	88.	,,	88 ,,	41·0	88
	NC4	600°/650°	8	,,	8 ,,	38·0	91
	NC5	685° C.		...	3 mins.	40·0	94
	NC	805° C.		...	6 secs.[1]	...	...
14·7 per cent. chromium	NR1	500°/550°	1740.	Withdrawn	10,000 hrs.[1]	...	...
	NR2	550°/600°	1728.	Broken	1,728 ,,	34·0	84
	NR3	600°/650°	79.	,,	79 ,,	37·0	85
	NR4	735° C.		...	3 mins.	36·0	91
	NR	800° C.		...	6 secs.[1]	...	...
High-speed	VA1/1	500°/550°	1717.	Withdrawn	81,000 hrs.[1]	...	...
	VA2/1	550°/600°	2002.	,,	25,000 ,, [1]	...	...
	VA2/2	600°/650°	380.	,,	4,500 ,, [1]	...	...
	VA3	650°/700°	564.	Broken	564 ,,	19·0	47
	VA1/2	700°/750°	21.	,,	21 ,,	24·0	60
	VA4	815° C.		...	3 mins.	32·0	82
	HS	955° C.[2]		...	6 secs.[1]	...	...
Nickel-chromium alloy (as cast)	CT5/1	500°/550°	521.	Withdrawn	...	...	...
	CT5/2	550°/600°	3604.	,,	108,120 hrs.[1]	...	...
	CT1	600°/650°	6041.	Broken	6,041 ,,	17·5	40
	CT5/3	650°/700°	901.	,,	901 ,,	14·5	23
	CT6	700°/750°	273.	,,	273 ,,	27·0	51
	CT8	895° C.		...	3 mins.	24·5	44
	CT4	925° C.[3]		...	1 min.	25·0	47
	V	965° C.[4]		...	6 secs.[1]	...	

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[1] Estimated.

[2] Test of another high-speed steel, of similar composition to VA, extracted from Fig. 1.

[3] This was a test carried out in the same way as CT8, except that the uniform heating ate was 100° C. every ten minutes. It is not elsewhere referred to.

[4] Test of another nickel-chromium alloy, extracted from Fig. 1.

extension-time curves would have the same form in each case. The estimates, which were necessarily obtained from carefully smoothed curves, are given exactly as calculated, but there are good reasons to suppose that the time is, in most cases, an under-

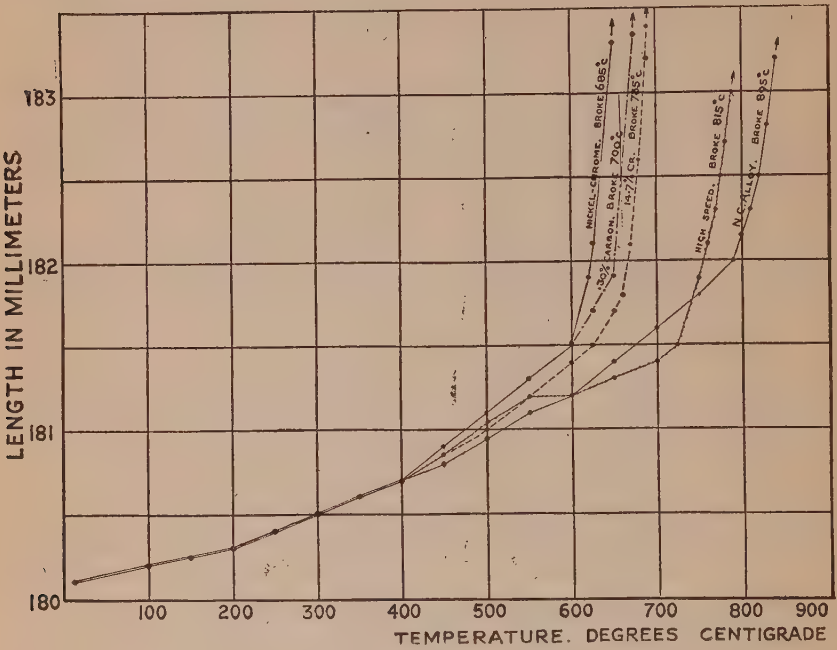

FIG. 4.

estimate, and, in any case, these estimates are only of general interest.

Beyond the general deduction that the temperature attained is higher as the duration at load is shorter, the relationship between these two variables will hardly be perceived from Table IV., but before passing on to consider this data in graphical form, an interesting feature of the ductility results may be noted. It will be seen that in all cases the reduction of area per cent. rises as the test-pieces are more rapidly broken, and that this is sometimes, but not always, accompanied by a corresponding rise in the elongation per cent. The three high-speed steel specimens, broken in 564 hours, 21 hours, and 3 minutes (at load), provide the most striking instance of this combined increase. Probably this is largely due to the higher temperature at which flow takes place, but possibly also the extent of the part played by plastic deformation, as opposed to purely viscous flow, is greater with more rapid loading.

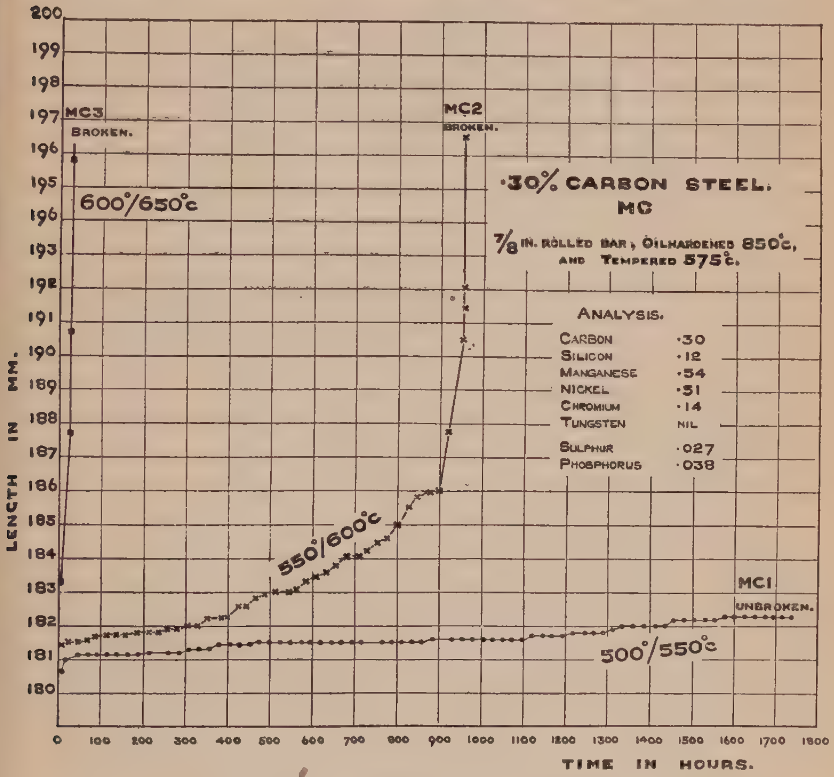

Fig. 5.

The data of columns 3 and 5, Table IV., are plotted in Fig. 10, having as co-ordinates "temperature" and "duration of loading," and in Fig. 11, having as co-ordinates "temperature" and "logs. of the duration of loading."

The latter diagram is by far the most helpful in comparing accurately the results of tests varying in duration between six seconds and many thousands of hours, but Fig. 10, which

---

[1] These diagrams are simplified by the exclusion of the carbon steel HTC.

scarcely needs explanation, well brings out the enormous influence of time in determining the temperature up to which each type of steel can support a given load (in this case 8½ tons per square inch), and, by implication, the load which can be borne at any given temperature. It is easy to deduce, for example, especially if Figs. 5 to 9 are consulted, that the maximum temperature up to which each of the typical steels will support a load of 8·5 tons varies, according to the conditions of loading, between the following figures :

	1.	2.
	Under a rapidly Applied Load, or for Short Duration of Loading.	When the Specimen is expected to Endure for considerable Periods without suffering Sensible Deformation.
	° C.	° C.
0·30 per cent. carbon steel .	775	500
Nickel-chromium steel . .	805	450
High-chromium steel . .	800	520
High-speed steel . .	900	575
Nickel-chromium alloy . .	965	600

It is largely because results of the type set out in column 1 are those usually published, while working conditions demand the data of column 2, that the author ventures to present this communication, the intention being rather to call renewed attention to the decidedly misleading character of the term "tensile strength," as applied to steel at elevated temperatures, and to throw doubt upon the figures quite commonly accepted as representing this doubtful property, than to present a mass of data.

Naturally the work was of a somewhat laborious character, but having carried out this series of tests at 8·5 tons per square inch the author proposes to put in hand supplementary tests, on the same lines, but at less and greater loads, which should enable an engineer to know exactly how various typical steels will behave under varying conditions of stress and temperature. In the meantime some very useful practical deductions may be drawn from these diagrams, and from Table IV.

Finally, the author proposes to discuss, very shortly, the true nature of the extension curves in Figs. 5 to 9, and particularly the indications of Fig. 11.

IV. THE FLOW OF STEELS AT A LOW RED HEAT.

Although all the long-duration tensile tests, described in the previous section, have been carried out at temperatures well below the critical ranges of the respective steels, the form of the curves in Figs. 5 to 9 points very strongly to the extension, and eventual rupture, of the test-piece, under unvarying load, being due almost completely to viscous flow. Whether plastic flow

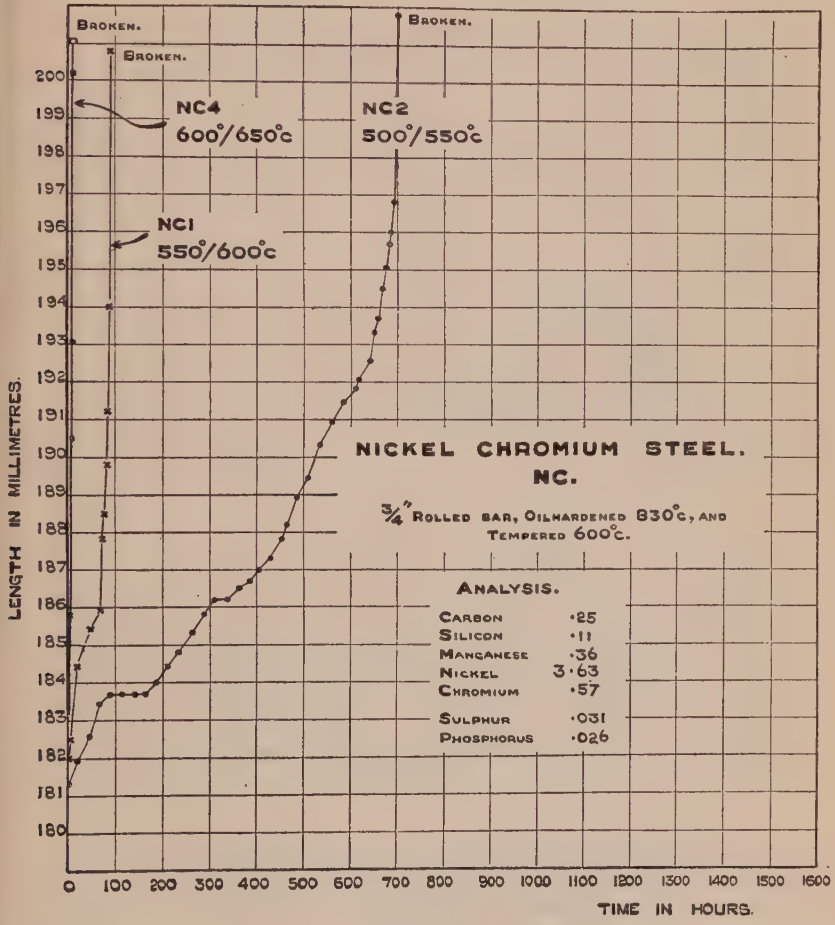

FIG. 6.

affects the shape of these curves, and if so, whether the data will prove sufficient to enable the plastic to be separated from the viscous flow, is a question to which the author has not yet found an answer ; but it does seem that a steady extension, under an unvarying load, such as that of the specimen CT1 of Fig. 9, Plate V., when a test-bar stretched continuously for 6041 hours, can only be due to truly viscous flow, with very little of the nature of ordinary plastic deformation entering into the case at all. This test is of a nickel-chromium alloy, but the curves of the various steels (NR2 of Fig. 7, for example) are little less remarkable, and all are more or less of the same form. It may be noted also that no test-piece which has been kept under stress for more than 1000 hours

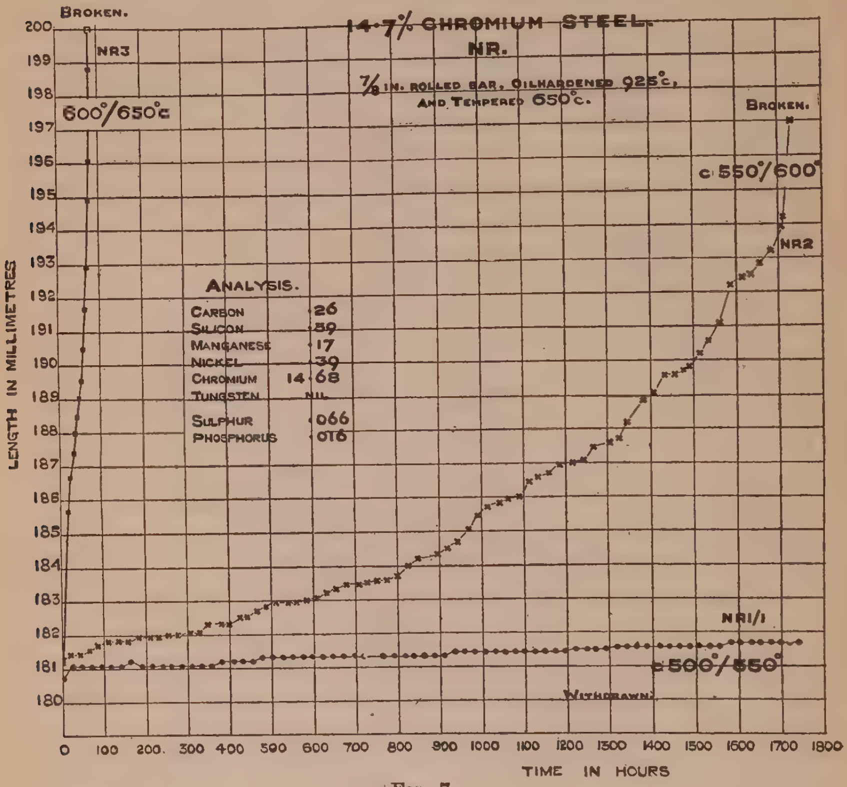

FIG. 7.

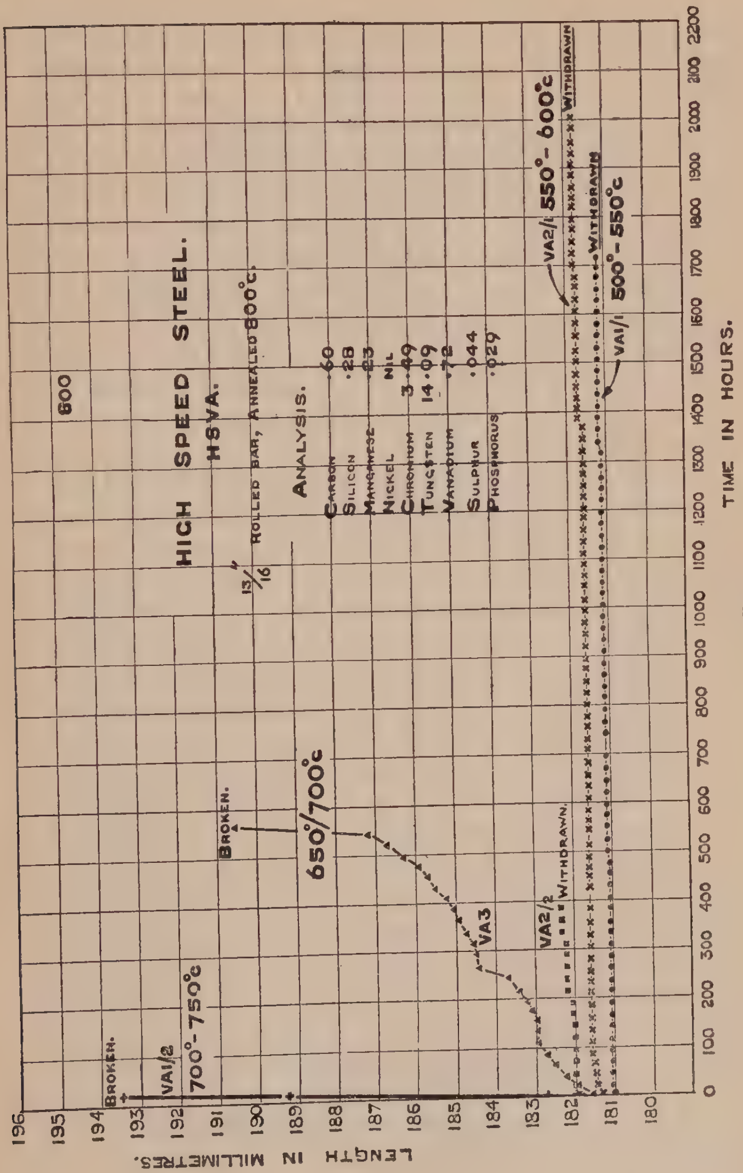
HIGH SPEED STEEL.
HSVA.
13/16 ROLLED BAR, ANNEALED 800°C.
ANALYSIS.
CARBON .60
SILICON .28
MANGANESE .23
NICKEL NIL
CHROMIUM 3.49
TUNGSTEN 14.09
VANADIUM .72
SULPHUR .044
PHOSPHORUS .029
600
BROKEN.
VA1/2
700°-750°C
BROKEN.
650°/700°C
VA3
VA2/2
WITHDRAWN.
VA2/1 550°-600°C
WITHDRAWN
WITHDRAWN
VA1/1 500°-550°C
LENGTH IN MILLIMETRES.
196
195
194
193
192
191
190
189
188
187
186
185
184
183
182
181
180
TIME IN HOURS.
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

Fig. 8.

has failed to show some movement, and that in some cases specimens which have been loaded for long periods have only stretched a very small total amount, but yet have made the extension in such a way as to suggest very strongly the ultimate formation of a curve of the same form as the others where fracture eventually occurred. NR/1, Fig. 7, is a case in point.

At the same time the author must admit that these extension curves, when plotted in terms of their logarithms, do not give perfectly straight lines. It should be borne in mind, however, that, during the progress of a test, the extension of the test-piece gradually disturbs the thermal conditions in the middle part of the gauge length. Further, all the long-duration tests have been carried out at temperatures well below the low limit of their respective critical ranges, so that the steel undergoing deformation is, mechanically, a mixture of harder and softer constituents. Very probably the shape of the extension curves, in these cases, is determined by the differing behaviour of the ferrite matrix and the carbide particles. Also, it should be noted, microscopic examination of longitudinal sections, prepared to include the fracture of ruptured test-pieces, has usually shown evidence of more or less general internal rupture. Whether this only occurs when the elongation has reached such a point that final rupture is imminent, has not yet been determined, but two characteristic cases are shown by Figs. 12 and 13, Plate VI., taken from the vicinity of the fracture of test-pieces VA3 and MC4 respectively. The former, taken from a high-speed steel which has broken after 564 hours continuous extension, shows numerous cavities produced along the threads of segregated tungstide globules ; while the other, from a carbon steel, actually at the fracture, shows many longitudinal ruptures, apparently produced by the sliding of one plane over another, usually assisted, and perhaps caused, by the presence of particles of non-metallic impurity. In the case of the cast nickel chromium alloy, rupture occurs between the grains of solid solution, where membranes of carbide, broken up into globules, have a decidedly weakening effect (Fig. 14, Plate VI.).

It is evident that such disturbing factors must make the interpretation of these extension diagrams a matter of very great difficulty, but the author hopes to proceed further with this aspect of the investigation in the future.

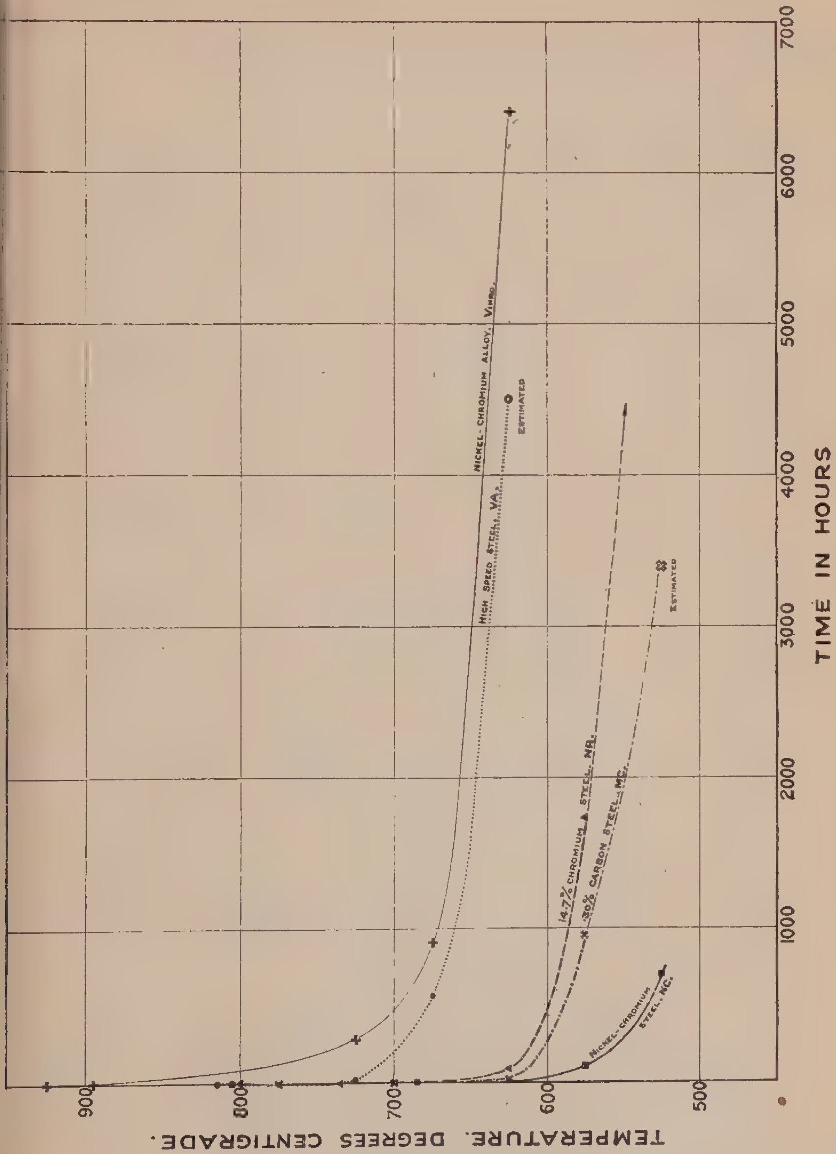
7000
6000
5000
4000
3000
2000
1000
TIME IN HOURS
900
800
700
600
500
TEMPERATURE. DEGREES CENTIGRADE.
NICKEL-CHROMIUM ALLOY, VIHRO.
ESTIMATED
HIGH SPEED STEEL, VA.
ESTIMATED
14.7% CHROMIUM ▲ STEEL, NR.
.30% CARBON STEEL, MC.
NICKEL-CHROMIUM STEEL, NC.

FIG. 10.

However, in spite of all this, and remembering that the points in Figs. 10 and 11 are based on *total* duration, during which the amount of deformation of the several test-pieces of each steel was not always the same, study of Fig. 11 leads to some quite interesting speculations.

Although the plotted points are too few in number to enable any definite conclusions to be drawn, they certainly tend to fall in straight lines, and making allowance for the disturbing factors previously mentioned, strongly suggest that the samples have behaved in accordance with the law governing the change of viscosity with temperature.

The author is very anxious not to overstrain the data embodied in Fig. 11, but it is a striking fact that the nickel-chromium alloy and the nickel-chromium steel give approximately parallel lines, which are inclined to the lines of the other three steels, these also being more or less nearly parallel.

Whether this difference indicates anything fundamental is not clear, but after all there is a difference in the behaviour of nickel steels as apart from carbon and chromium steels when subjected to tensile stress even in the cold.

Fig. 11 also explains why the nickel-chromium alloy, which has much the same endurance as high-speed steel at 625° C., should be so very much more difficult to forge at 1000° C., when, under a hammer, it appears to be very much harder than high-speed steel. Much the same remark will apply after a comparison of the 0·30 per cent. carbon and nickel-chromium steel lines. Although the latter material certainly deforms more readily under constant load at, say, 575° C., most forgemen would describe it as the harder steel of the two. One very important practical consideration arises out of this : that in selecting material for resistance to stress at elevated temperatures the nature of the stressing must be brought into account.

Thus, for example, the nickel-chromium alloy is obviously far better able to resist occasional and intermittent heavy loads at high temperatures than is high-speed steel, but at much lower temperatures the latter steel shows equal endurance. It should be added, however, that when resistance to oxidation becomes a factor the alloy scores heavily, but this aspect of the matter is dealt with in Part II.

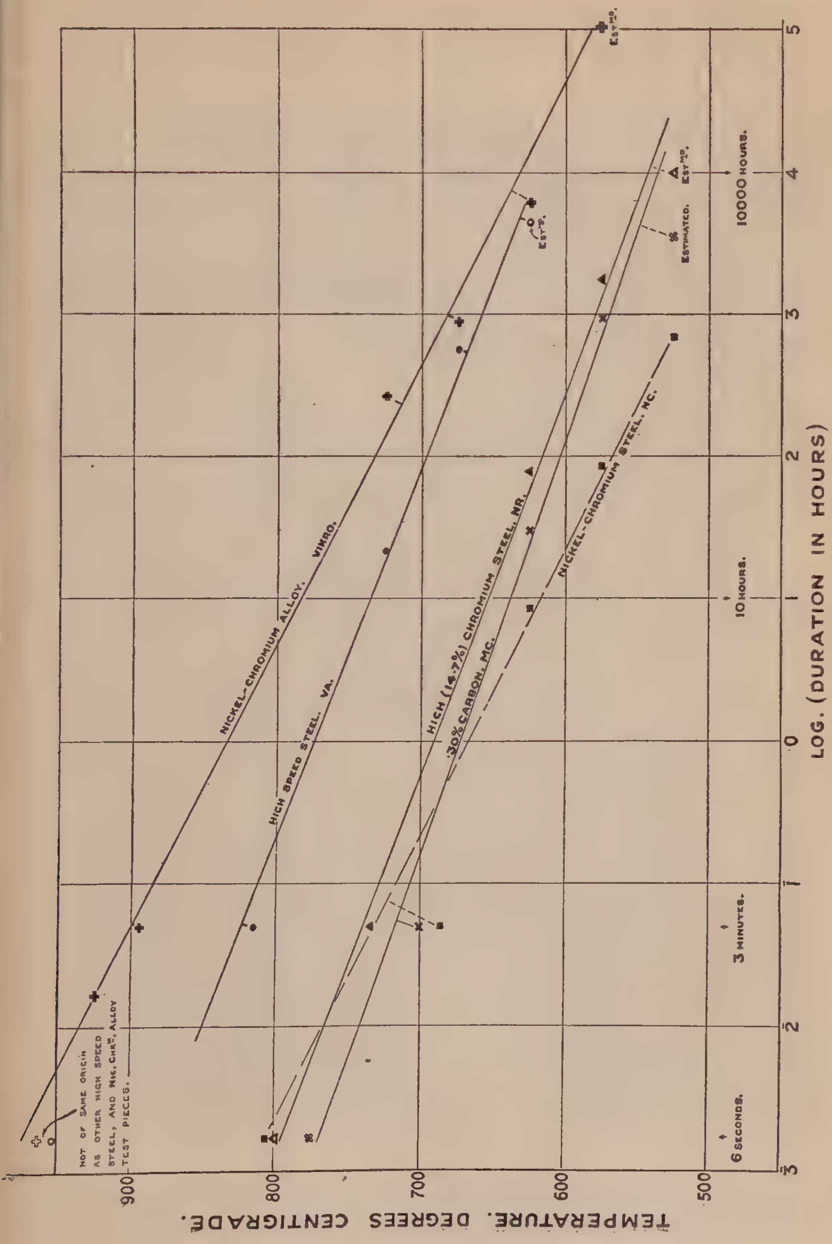
NICKEL-CHROMIUM ALLOY. VIKRO.
HIGH SPEED STEEL. VA.
HIGH (14·7%) CHROMIUM STEEL. NR.
·30% CARBON. MC.
NICKEL-CHROMIUM STEEL. NC.
NOT OF SAME ORIGIN AS OTHER HIGH SPEED STEEL, AND NIC. CHR^M. ALLOY TEST PIECES.
EST^D.
EST^MD.
ESTIMATED.
6 SECONDS.
3 MINUTES.
10 HOURS.
10000 HOURS.
900
800
700
600
500
TEMPERATURE. DEGREES CENTIGRADE.
3̄
2̄
1̄
0
1
2
3
4
5
LOG. (DURATION IN HOURS)

FIG. 11.

Finally, although the author does not wish to trespass upon the domain of the mathematical physicist, it may be asked, whether, if the lines in Fig. 11 are really straight, the same law will continue to apply down to very much lower temperatures.

If so, there seems to be no reason why a cold test-piece of, say, the 0·30 per cent. carbon steel, should not, in time, be pulled in two by a load of 8½ tons per square inch.

Production of the 0·30 per cent. carbon steel line down to the atmospheric temperature actually comes out at about log. 19 (hours), or roughly one thousand million million years. However, these rather wild speculations are getting far from the original purpose of this investigation.

PART II.

NOTE ON THE SCALING OF STEELS AT ELEVATED TEMPERATURES.

1. *Introductory.*

An important factor in the selection of steel for use in many heated structures, exposed to the air or to oxidising gases, is the extent to which weight is lost by "scaling."

Although the remarkable resistance to oxidation offered by certain nickel-chromium alloys, and in somewhat less degree by high-chromium steels, is fairly generally known, there is remarkably little published information regarding the relative behaviour, in this respect, of various types of steel.

Because such comparisons as have been published are usually of a somewhat arbitrary nature,[1] it may be of interest to give the results of an investigation to determine, for a selection of typical steels, the relationship between the rate of scaling, stated as loss of weight in grammes per square inch of superficial area per hour, and the temperature.

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[1] L. Aitchison, "Valve Failures and Valve Steels in Internal Combustion Engines," *Journal of the Institution of Automobile Engineers*, 1919–1920, vol. xiv. p. 53.

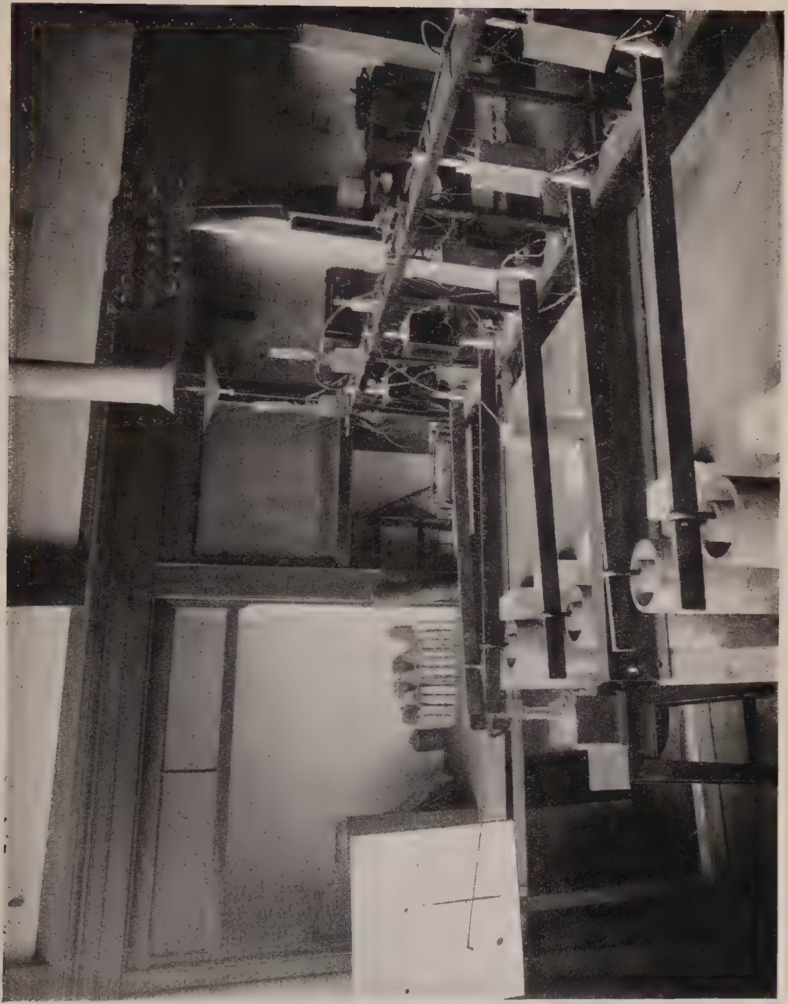
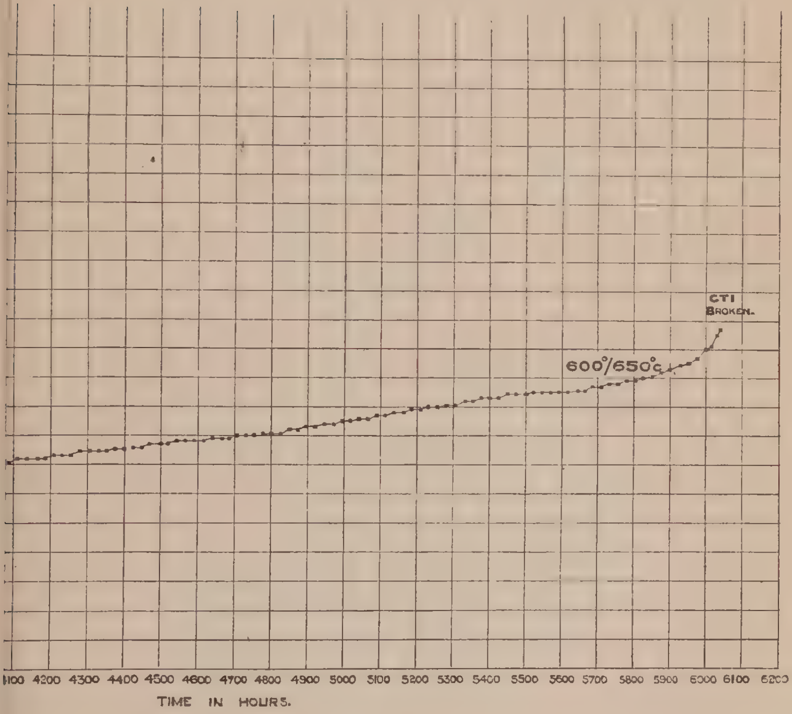


FIG. 2. Tensile testing apparatus employed.

[*To face p.* 128.

J. H. S. Dickenson's Paper.—Plate V.



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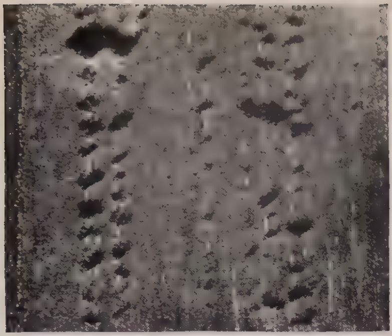

FIG. 12. Near fracture of test piece VA3. × 100.

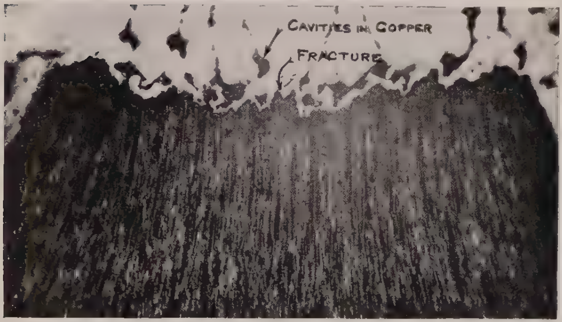
CAVITIES IN COPPER
FRACTURE

FIG. 13. Fracture of test piece MC4. × 50.

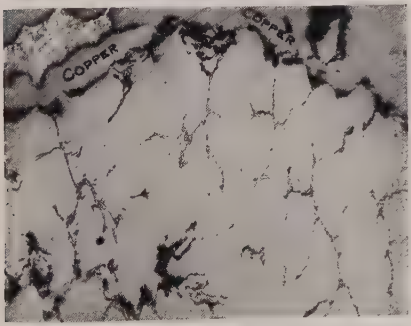
COPPER
COPPER

FIG. 14. Rupture of cast nickel-chromium alloy at carbide network. × 50.

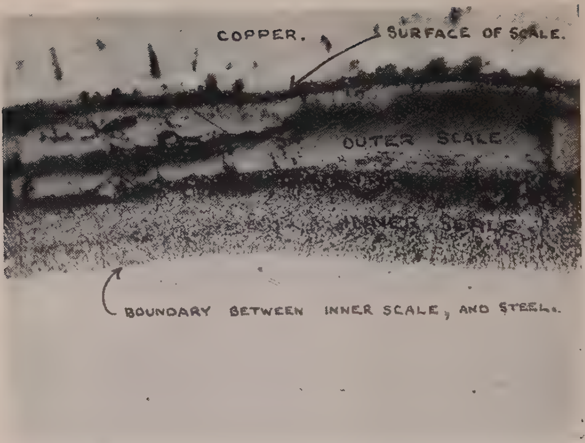
COPPER.
SURFACE OF SCALE.
OUTER SCALE
INNER SCALE
BOUNDARY BETWEEN INNER SCALE, AND STEEL.

FIG. 20. Double scale on surface of 25% nickel steel.
Unetched. × 50.

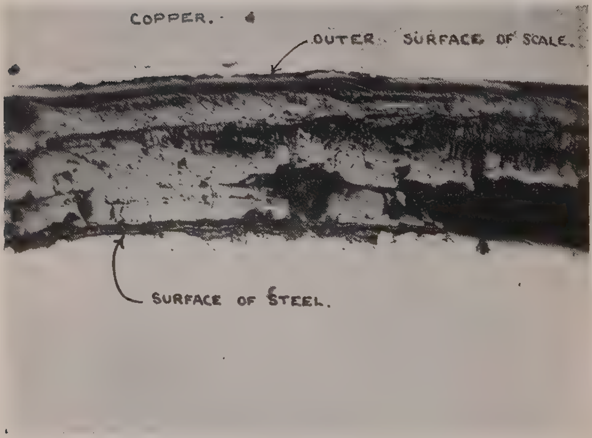
COPPER.
OUTER SURFACE OF SCALE.
SURFACE OF STEEL.

FIG. 21. Scale on surface of 0.30% carbon steel.
Unetched. × 50.

[*To face p.* 129.

2. *Selection of Typical Steels.*

Eight typical steels, and one sample of a nickel-chromium alloy, having analyses as in Table V., were selected for examination. It will be observed that several of these steels were used in the experiments previously described. The alloy was rolled to $\frac{3}{4}$ inch diameter; all the others to $\frac{5}{8}$ inch diameter, round.

3. *Details of Experiment.*

From each sample of steel nine cylinders, each 0·500 inch diameter by 2·00 inch long, were machined, polished with emery, and weighed.

A complete collection of test cylinders, one of each steel, has been heated for a total time of 100 hours, within each of the following temperature ranges:

In an Electric (Nichrome Wound) Muffle Furnace. Internal dimensions, 8½″ × 6″ × 3½″.			In a Gas-Heated Muffle Furnace. Internal dimensions, 6″ × 4″ × 3″.		
Collection	A	550° C. to 600° C.	Collection	F	850° C. to 900° C.
,,	B	650° C. ,, 700° C.	,,	G	920° C. ,, 970° C.
,,	C	700° C. ,, 750° C.	,,	H	1000° C. ,, 1050° C.
,,	D	750° C. ,, 800° C.	,,	I	1075° C. ,, 1125° C.
,,	E	850° C. ,, 900° C.			

In order to maintain, throughout the 100 hours, a practically uniform rate of oxidation, which slows down as adhering scale increases in thickness, the heating was carried out in eighteen periods of approximately equal length, of about 5½ hours each, the specimens being scraped free of scale, and weighed, after each cooling. This had the further advantage of permitting the nine specimens of each collection, which were placed about ½ inch apart, on end, in a ring round a centrally placed thermocouple, to be moved one place, in a clockwise direction, after each removal. Each test cylinder thus made two complete circuits during the 100 hours, so that any possible inequalities which might have arisen from slight temperature variations, or air currents from a small opening left in the muffle front, were eliminated.

TABLE V.

Symbol.	Class of Steel.	Analysis.									Heat-Treatment.
		C.	Si.	Mn.	S.	P.	Ni.	Cr.	W.	V.	
MC	0·30 carbon . .	0·30	0·12	0·54	0·027	0·038	0·51	0·14	...	...	Oil-treated
6H	0·45 carbon . .	0·45	0·37	0·79	0·022	0·024	...	0·02	...	...	,,
G	Nickel-chromium .	0·28	0·20	0·31	0·034	0·033	3·70	0·71	...	...	,,
CN	5 per cent. nickel .	0·10	0·06	0·12	0·032	0·036	5·43	0·14	...	...	Normalised
N	25 per cent. nickel .	0·27	0·16	1·21	0·022	0·024	24·36	0·06	...	...	Water-quenched
HSO	High-speed . .	0·65	0·30	0·22	0·041	0·027	0·12	3·73	13·68	...	Annealed
HSV	High-speed . .	0·85	0·40	0·23	0·044	0·022	0·08	4·19	18·36	0·96	,,
NR	High-chromium. .	0·26	0·59	0·17	0·066	0·016	0·39	14·68	...	...	Oil-treated
V	N.C. alloy . . .	0·29	0·87	1·80	0·050	0·018	65·05	11·7	...	...	Water-quenched

Although it was found impracticable to maintain the temperature, which was recorded by a Cambridge thread recorder, perfectly constant in the middle of the temperature range, it may be taken that the limits (50° C.) were never exceeded, and that the actual mean temperature of the trials may be fairly stated as 575°, 725°, and so on.

4. *Statement of the Results Obtained.*

It may be stated at the outset that the two carbon steels showed almost exactly the same scaling rates throughout, as also did the two high-speed steels. It is therefore proposed to simplify the diagrams by giving, of these, only the results obtained from the 0·30 per cent. carbon steel, and the lower tungsten high-speed steel (HSO). The 5 per cent. nickel steel and the nickel-chromium steel (G) also behaved so very much alike that only the results from the former are given.

It is proposed to report the results obtained at the lower and upper ranges somewhat differently.

None of the specimens heated in the four temperature ranges up to 750°–800° C. scaled so rapidly that the weight after successive heatings, plotted against the time, showed any serious departure from a straight line. In these cases, therefore, the rate of loss by scaling, expressed as grammes per square inch per hour, may be readily calculated, with sufficient accuracy, from the total loss of weight in 100 hours and the original surface area, the results being set out in Table VI., along with the corresponding percentage loss of weight in 100 hours.

This table also gives the figures for the two collections heated, one in the gas and the other in the electric furnace, in the 850° to 900° C. range, but at this temperature certain specimens did suffer appreciable reduction of surface area, and the rate of loss was calculated from the weight shown at fifty hours on the smoothed weight-time curve, the first half of this curve being sufficiently nearly straight in all cases.

As the two series at the range 850° to 900° C. were carried out with the object of linking together the lower temperature series, heated in an electric furnace, where the specimens were surrounded by air, and the higher series heated in the less pure

TABLE VI.

Symbol.	Class of Steel.	575° C. 550° to 600° Electric.		675° C. 650° to 700° Electric.		725° C. 700° to 750° Electric.		775° C. 750° to 800° Electric.		875° C. 850° to 900° Electric.		875° C. 850° to 900° Gas.	
		Loss by Scaling.		Loss by Scaling.		Loss by Scaling.		Loss by Scaling.		Loss by Scaling.		Loss by Scaling.	
		Weight per Cent.	Rate.[1]	Weight per Cent.	Rate.[1]	Weight per Cent.	Rate.[1]	Weight per Cent.	Rate.[1]	Weight per Cent.	Rate.[1]	Weight per Cent.	Rate.[1]
MC	0·30 per cent. carbon .	2·0	0·0027	6·3	0·0080	13·1	0·018	25·4	0·036	59·5	0·100	62·9	0·094
G	Nickel-chromium .	2·0	0·0027	7·4	0·0095	10·8	0·014	17·7	0·025	46·0	0·08	48·2	0·070
N	25 per cent. nickel .	0·4	0·0005	1·6	0·0022	3·9	0·005	7·5	0·011	24·1	0·054	14·4	0·023
HSO	High-speed . .	0·7	0·0011	2·7	0·0038	4·3	0·006	6·9	0·010	30·6	0·054	42·3	0·06
NR	High chromium .	nil	nil	0·4	0·0005	0·8	0·001	1·2	0·002	5·0	0·007	5·9	0·008
VIKRO	N.C. alloy . . .	nil	nil	nil	nil	0·1	...	0·2	...	1·1	0·0017	0·8	0·0011

---

[1] Rate means loss of weight in grammes per square inch per hour.

atmosphere of a gas muffle, it is desirable to consider the results somewhat closely.

It will be noted that the carbon steel, nickel-chromium steel, and high-chromium steel specimens of the two series give remarkably similar results,[1] but that the 25 per cent. nickel steel and high-speed steel show marked differences. Of these the former discrepancy is readily explained by a peculiarity in the scaling of high-nickel steel, which will receive some attention later; but the author is still unable to explain why the high-speed steel specimen, heated at 875° C. in the gas furnace, should have lost weight at about the same rate as the corresponding electrically heated specimen during the first fifty hours, and afterwards have scaled so much more rapidly. However, after careful examination of the plotted weight-time curves the scaling rates were determined as shown in Table VI., and are certainly not far from the truth.

It appears that, on the whole, the rate of scaling at 875° C. is much the same in the two types of furnace, at any rate when the gas muffle front is slightly open and the burners are receiving full air, as in the present case, so that the lower and upper series may thus be considered to be satisfactorily linked.

The great rapidity with which many of the specimens scale away at 920° to 970° C. and upwards, and the correspondingly rapid diminution of the surface area, makes it necessary to calculate the loss of weight per square inch per hour on quite short time intervals, as will be obvious from Figs. 15, 16, and 17, on which all the successive weighings of each specimen, of the 945° C., 1025° C., and 1100° C. ranges, respectively, are plotted against the time of heating. Most of the plotted lines show very considerable curvature, and not a little irregularity, distinct waves, due to the rotation of the specimen round the muffle floor, being observable in some cases, but the true form of the curve is quite obvious in all cases.

These diagrams bring out, among other things, the remarkable resistance to oxidation of the nickel-chromium alloy, and a curious stepping in the 25 per cent. nickel line, but the principal object of this work, an exact comparison of the different steels, is better

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[1] The apparent slight discrepancy between scaling rates and percentage loss of weight arises because the former is based on the first fifty hours, and the latter on the total time.

TABLE VII.

Symbol.	Class of Steel.	Scaling Rate in Grammes per Square Inch per Hour at Mean Temperature Indicated.								
		Electric Furnace.					Gas Furnace.			
		575° C.	675° C.	725° C.	775° C.	875° C.	875° C.	945° C.	1025° C.	1100° C.
MC	0·30 per cent. carbon	0·0027	0·0080	0·018	0·036	0·100	0·094	0·160	0·37	0·55
G	Nickel-chromium	0·0027	0·0095	0·014	0·025	0·080	0·070	0·130	0·32	0·60
N	25 per cent. nickel	0·0005	0·0022	0·005	0·011	0·054	0·023	0·100	0·21	0·41
HSO	High-speed	0·0011	0·0038	0·006	0·010	0·054	0·060	0·095	0·25	0·47
NR	High-chromium	nil	0·0005	0·001	0·002	0·007	0·008	0·017	0·14 (?)	0·27
VIKRO	N.C. alloy	nil	nil	...	...	0·0017	0·0011	0·0014	0·002	0·008

A specimen of NR, specially heated at a mean temperature of 980° C., gave a scaling rate of 0·028.

afforded by the scaling rates derived from these diagrams. These are set out, along with those of the lower temperature ranges, in Table VII., and are plotted in Fig. 18.

To obtain the rate of loss of weight, in grammes per square inch per hour, each plotted line in Figs. 15, 16, and 17 was carefully smoothed to give an obvious and natural curve for the total time, by means of a flexible lancewood strip.

The loss of weight on the first ten hours of this line, this length of the curve being always nearly straight, even in the most rapidly scaled specimens, was usually taken as the basis for the calculation; but in some cases specimens were measured at various periods, so that the loss of weight for a short period immediately previous, or subsequent, to each measurement of superficial area could be taken from the smoothed curve, and a check calculation of rate be made. It was found that until the specimen was reduced to very small diameter, say well under 0·10 inch, when an increase occurs, the scaling rates obtained by this method were remarkably consistent.

Examination of Fig. 18 shows that the connection between the electric and gas-heated series, at 875° C., fits in very well with the general shape of the curves. This diagram needs very little discussion, since it shows at a glance the temperature at which scaling becomes appreciable on each of the six steels examined. If, for example, a scaling rate of 0·005 gramme per square inch per hour were to be fixed as the maximum allowable, then nickel-chromium and carbon steel could not be used over 620° C., high-speed steel could go up to 710° C., high-chromium steel (stainless) up to 840° C., and the nickel-chromium alloy up to no less than 1070° C.

The practical uses of this diagram are, in fact, sufficiently obvious, but it may be noted that, over 700° C., the different steels maintain the same order as the temperature rises.

When the logarithms of the scaling rates were plotted against the temperature, as shown by Fig. 19, it was found that the plottings of each steel fell with reasonable precision along a straight line, particularly the lower points obtained in the more equable electric furnace. Irregularities in some of the upper points are quite likely to be due to inequalities in the working of the gas

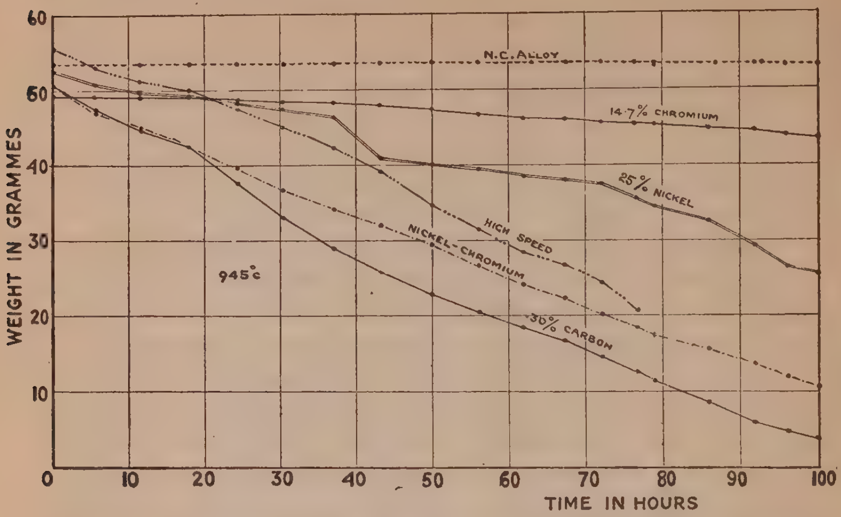

DIAGRAM TO SHOW THE LOSS OF WEIGHT, BY SCALING AT 945°c

Fig. 15.

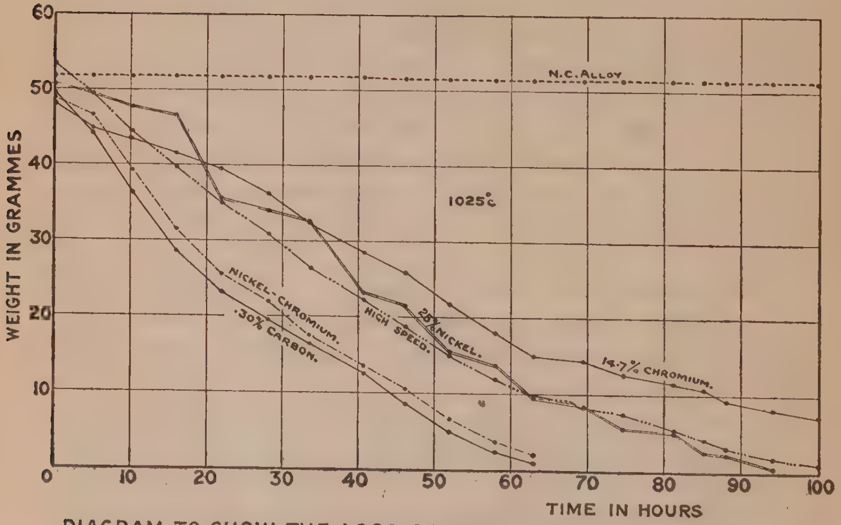

DIAGRAM TO SHOW THE LOSS OF WEIGHT, BY SCALING AT 1025°c

Fig. 16.

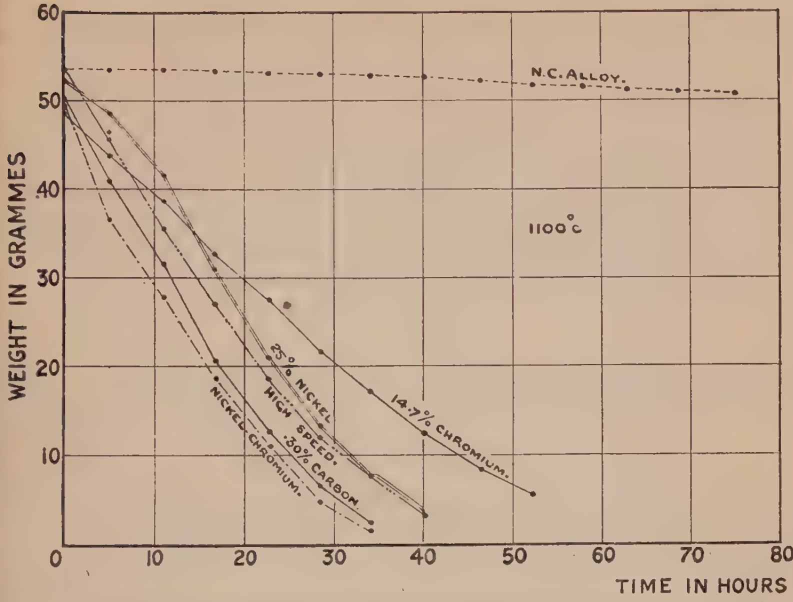

DIAGRAM TO SHOW THE LOSS OF WEIGHT, BY SCALING AT 1100°C

Fig. 17.

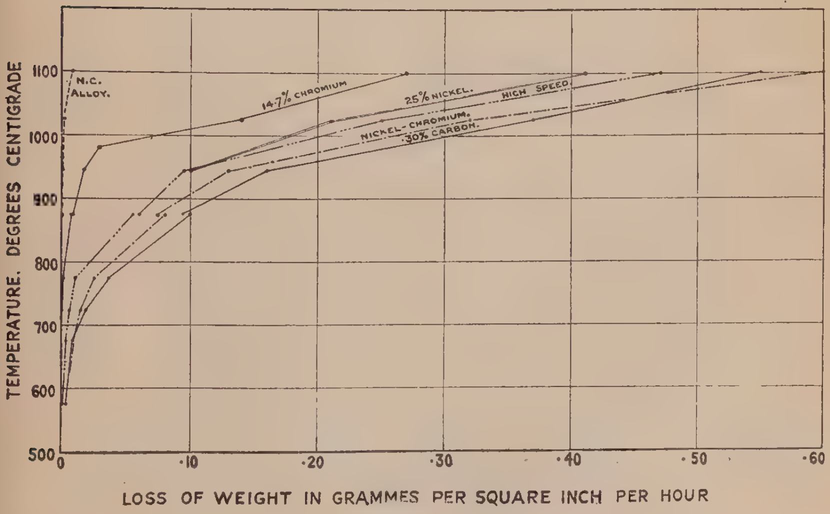

Fig. 18.

furnace, and indeed the point at 1025° C. looks to be out of place even as plotted in Fig. 18.

Fig. 19 suggests that the relationship between the rate of oxidation and the temperature is governed by a simple law, which is the same for all the steels examined. In actual fact, if the same data are plotted in terms of their logarithms, taking the logs. of the absolute temperatures and the logs. of the scaling rates as co-ordinates, the points still fall on to reasonably straight lines, in which case the relationship may be expressed as:

$$R \propto T^n,$$

where R is the rate of oxidation and T is the temperature.

4. *Micro-Examination.*

A brief account may be given of the micro-examination of a complete series of specimens, heated in the electric furnace at 900° C. for twenty-four hours, and then heavily copper-plated, to hold the scale in position before sectioning.

These showed a marked difference in the formation of the scale upon the carbon, high-speed, and high-chromium steels, and the three steels containing nickel. The latter all showed the characteristic lower layer, containing a large proportion of metal, described and explained by Stead.[1] In the case of the 25 per cent. nickel steel, the lower layer is particularly well defined, as shown by Fig. 20, Plate VII., this explaining the "stepping" in the curves of this steel in Figs. 15 and 16. Although the outer, completely oxidised layer easily shells off, the inner is strongly adherent, and cannot be removed until it has reached considerable thickness. As this layer is distinctly malleable, and presents a very smooth metallic appearance, after the outer scale has been knocked away, it is easy, mistakenly, to suppose that no scale remains. This may account for several cases, of which the author has heard, where heated parts made of 25 per cent. nickel steel have apparently behaved very well for a time, and then suddenly collapsed. The carbon steels form a well-defined and completely oxidised scale, but, as illustrated by Fig. 21, Plate VII., there is some

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[1] Stead, "Notes on Nickel Steel Scale," *Journal of the Iron and Steel Institute*, 1916, No. II. p. 243.

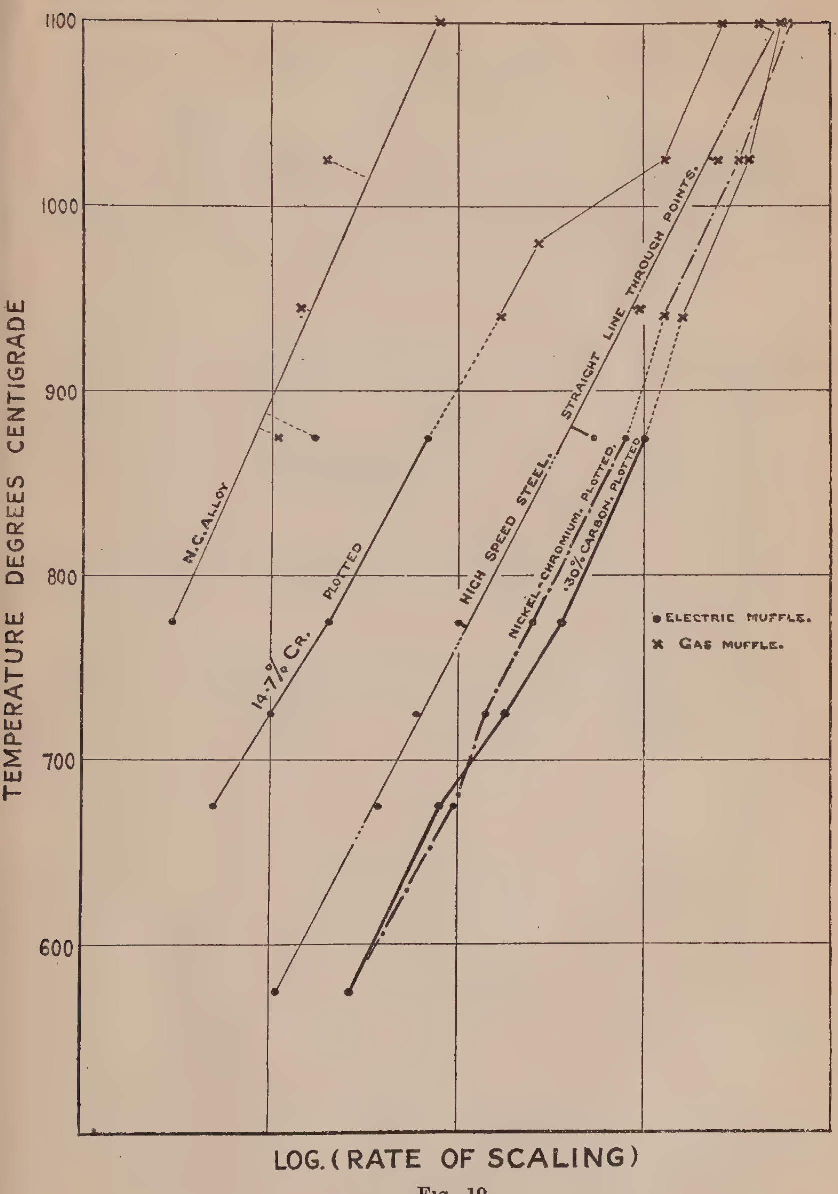
1100
1000
900
800
700
600
TEMPERATURE DEGREES CENTIGRADE
LOG. (RATE OF SCALING)
N.C. ALLOY
14·7% CR. PLOTTED
HIGH SPEED STEEL. STRAIGHT LINE THROUGH POINTS.
NICKEL-CHROMIUM. PLOTTED.
·30% CARBON. PLOTTED
● ELECTRIC MUFFLE.
× GAS MUFFLE.

FIG. 19

penetration of oxide membranes, apparently along the crystal junctions, into the underlying steel. The scale formed on the high-speed steel is very similar, but is even more cleanly separated, and there is little or no penetration of oxide below the smooth steel surface. This scale shows separation in differently coloured layers, but there is no band containing unoxidised metal.

It remains to be added that the oxide layer on the high-chromium steel sample was barely visible between the copper and the steel, while that on the nickel-chromium alloy was so thin as to be quite unrecognisable on the section.

In concluding, the author wishes to express his gratitude to a number of his colleagues, whose friendly assistance has been of great value in carrying out this work. He would like particularly to thank Mr. J. H. Huxley, A.R.S.M., F.I.C., for the chemical analyses, and Mr. J. P. Nicholson for general assistance in the mechanical testing. He is also glad to record his indebtedness to his assistants, and in this connection more particularly to Mr. B. Ludgate, who has cheerfully sacrificed a portion of each Sunday, for more than a year, in order to make the daily measurements of extension.

Finally, he begs to express his thanks to Mr. William Clark, Director of Messrs. Vickers Limited, for permission to publish the results of these investigations.

DISCUSSION.

Mr. Harry Brearley (Member of Council), in opening the discussion, said there could be no question in the mind of any individual who had read the paper but that Mr. Dickenson was a man of infinite patience. The results he had set out in the paper appeared to extend very considerably the knowledge of the properties of steels at high temperatures, over and above that type of knowledge that could be obtained from the testing of an ordinary tensile test-piece. At the same time, he would suggest that Mr. Dickenson had been rather severe in his criticism of people who had devoted their attention to the making of tensile test-pieces at high temperatures, by characterising the results of such tests as misleading and meaningless. He took it that Mr. Dickenson did not suggest that a material which had a tensile strength, say of 20 tons at 650° C., was not, so far as any form of stress was concerned, more resisting than a steel which was found to have a tensile strength of say 10 tons at 650° C. One thing missed very much from Mr. Dickenson's paper was a form of stress strain diagram of material taken at high temperatures. In discussing stress strain diagrams in relation to tensile tests, it ought to be remembered that after all the tensile test was a conventional test. It originated, he believed, in days when the ordinary form of structural material to which it was applied was wrought iron, and in relation to wrought iron it really meant something that it did not mean in relation to steel, so that it was a test that had been inherited, so to speak, in the steel age from the iron age. When an ordinary stress strain diagram, taken from a piece of steel pulled cold, was examined, it would be found to be made up of different parts. After the yield point had been passed the stress rose very considerably to a maximum which it had been agreed to call the maximum stress or the tensile strength. Then the diagram bent down again; but if the diagram were plotted, not on the tensile strength per unit area of the original test-piece, but on the actual area of stress at any particular moment, instead of that curve, after having passed the yield point, rising and falling, it would continue to rise. The conditions under which Mr. Dickenson had been making his tests were altogether different from those under which a tensile test-piece was pulled in the cold. If Mr. Dickenson were to plot, or autographically draw, a stress-strain diagram of a piece of steel at some temperature above red heat, he would probably find that he did not get any maximum stress in the sense that a maximum stress was registered on an ordinary stress-strain diagram, but that as soon as he had reached a particular unit stress (depending on the rate at which he was loading and the kind of steel that he was working with), the stress curve would simply bend down again. He (Mr. Brearley) was not sure, but he rather fancied that if an autographic stress-strain diagram of hot steel were carefully made it would be found to contain in itself the suggestion of almost the whole of the information which Mr. Dickenson had so laboriously collected.

The paper had focussed attention on the behaviour of structural parts at high temperatures. He thought that for most members interest in the properties of steels at high temperatures was confined to the relative difficulty or ease with which they could be deformed under rolls and hammers, and in that particular respect he would like to draw Mr. Dickenson's attention and the attention of the members to the results of a number of tests which could be very simply made, but which were extremely difficult to explain. He produced a ¼-inch steel bar—almost any kind of steel, so far as he knew, would serve—which had been made hot at one end, that was to say, it had been raised to a temperature of about 1000° to 1100° C. at one end, and then the heat had been allowed to taper down until within 3 or 4 inches from the colder end it was perhaps about 600° C. That bar was gripped at the hot end in a vice, and then the other end was put in an ordinary joiner's brace, and the bar was twisted. It would naturally be expected from all tensile determinations made on steels at high temperatures that the bar would twist most where it was hottest. What happened in nearly all cases was that where it was hottest there was a twist of a short pitch; then, somewhere down the metal, came a twist of a longer pitch, and finally there was a twist of the shortest pitch of all where the end was coldest. It was very easy to make that test, but extremely difficult to explain it. He could not explain it, but he submitted it in the hope that Mr. Dickenson might be able to do so. The observation had been made many times under industrial conditions during the manufacture of augurs and twist-drills.

Mr. J. H. WHITELEY (Saltburn) said that Mr. Dickenson, in dealing with the scaling of steels, in the second part of the paper, had arrived at what might almost be called a fortuitous exponential function, as shown in Fig. 19. That such excellent curves should have been obtained by plotting the results in that manner seemed remarkable when the conditions of the experiments were examined. In the first place, the temperatures were far from constant during the heatings, and the amount of air passing through different parts of the two types of furnaces used also probably varied. Mr. Dickenson had recognised that, and had endeavoured to eliminate errors due to those causes by changing the positions of the pieces in the furnace after each weighing. Again he (Mr. Whiteley) would ask the author whether, in the five and a half hours' heating given, he took the precaution to see that scale did not fall off some of the pieces. Five and a half hours between say 800° and 900° C. was a long time to heat the samples, especially plain carbon steels which scaled readily, and if the heavy scale which formed were not closely adherent, some might easily be lost. Further, as Mr. Dickenson had mentioned, particles of metallic iron could be included in the scale, more especially in the case of the alloy and nickel steels, where also the scale could not be entirely removed because it was embedded in the iron at the surface. Those effects would also tend to cause divergencies from the true results. The chief point he (Mr. Whiteley) wished to refer to, however, was Mr. Dickenson's statement that the rate of oxidation diminished as the scale increased in thickness. He wished to ask on what ground he based that statement, because it appeared to him (Mr. Whiteley) that the curves in Fig. 19 were much more readily explicable if the rate of oxidation did not appreciably alter as the scaling progressed. In connection with that matter, the question arose as to how the oxygen reached the surface of the metal below the scale. He believed that, when once a coating of oxide had formed, any further scaling was due to a reduction of ferric oxide to a lower oxide by the metallic iron. Of course, there was the possibility that oxygen might diffuse through the scale and so act directly upon the iron, but, since the scale itself could readily absorb oxygen, the balance of evidence seemed to be in favour of the view that scale was continually increased by the reducing action of the iron upon its own oxide. Now that reaction even at high temperatures was not very rapid, and at lower temperatures it was undoubtedly slow. If, therefore, the rate at which oxygen could form ferric oxide adjacent to the metal were as quick or quicker than the rate of reduction by the iron, the speed of scaling would continue to be approximately uniform, and would not diminish seriously as the thickness of the scale increased. If that were the case, as seemed probable, it would help largely to account for the excellent curves Mr. Dickenson had found. The matter was one which, in studying the question of scaling, needed to be definitely settled for each kind of steel employed.

CORRESPONDENCE.

Professor J. H. Andrew (Glasgow) wished to ask Mr. Dickenson whether he had made an analysis of the oxides formed on heating, also whether he had noticed any difference in the tenaciousness of the oxides formed at different temperatures. He (Professor Andrew) invariably found that in the rolling of certain classes of material, the oxide would sometimes flake off under the rolls, and sometimes stick and become rolled in. That he had imagined was due in some way to the composition and therefore the fusion point of the oxide. Could Mr. Dickenson furnish any data on that matter. The paper was a most valuable contribution and of the usual high standard of Mr. Dickenson's other contributions.

Mr. P. CHEVENARD (Imphy Steel Works, France) wrote that Mr. Dickenson's paper recalled to his mind the researches carried out, on the same subject, at the Imphy Steelworks of the Commentry-Fourchambault & Decazeville Company. Those researches had led to the introduction of steel alloys endowed, at high temperatures, with remarkable properties.

The problem of producing alloys of high tenacity when heated was investigated in 1913 at the Imphy Steelworks. As such products were required to be almost rustless and to have reversible properties, the question of solving that problem with hardened high-speed steels was discarded. Such steels were, indeed, susceptible to oxidation, while the prolonged maintenance of a temperature above 550° to 600° led to the gradual destruction of the hardening effects, a tendency which was, moreover, seriously increased if the temperature at which such steels were to be employed should accidentally be exceeded. In 1913, therefore, when the Company was preparing a series of ternary ferro-nickel alloys for the investigations of Mr. C. E. Guillaume, attention was attracted to the exceptional difficulties experienced on forging certain iron-nickel chromium alloys rich in nickel and chromium, which, on being heated to the temperatures customarily employed for forging hard steels, could scarcely be shaped under the steam-hammer. That led to a number of investigations being made on the mechanical properties of pure iron-nickel and other ternary alloys at high temperatures.

To begin with, ordinary tensile tests were employed on test-bars heated electrically, the testing machine being arranged so as to attain a constant rate of application of tensile stress during each experiment. That rate was 5 millimetres per minute. The data given by those tests was plotted in diagrams in which the temperatures were taken as abscissæ, while the ordinates were the mechanical properties displayed, such as tenacity, elongation, &c. One of those diagrams was reproduced by Mr. L. Guillet in 1914 in the *Revue de Métallurgie*,[1] and related to a quaternary alloy with the commercial description ATG, and containing approximately, in addition to iron, 60 per cent. of nickel, 10 per cent. of chromium, and 4 per cent. of tungsten.

From the very start it was seen that the tensile test results were dependent, to a very great extent, on the rate of stressing, at high temperatures, when the metal was viscous. It was determined, therefore, to make viscosity tests. The tensile tests were, however, continued, for, as they were carried out under strictly constant con-

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[1] L. Guillet, "Alloys possessing Remarkable Properties at Very High and Very Low Temperatures," p. 969, *et seq.*

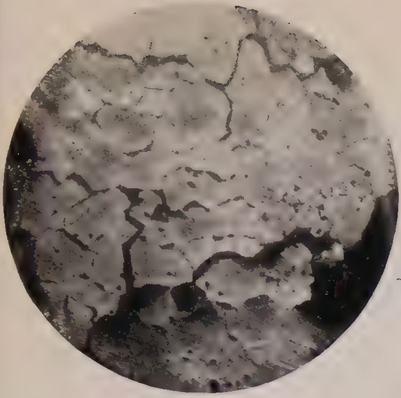

FIG. A. Mild Steel as altered during operations.

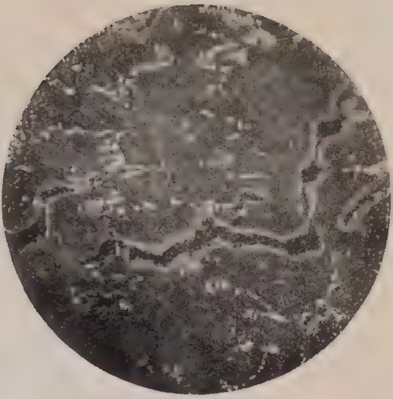

FIG. B. ATG Metal as altered during operations.

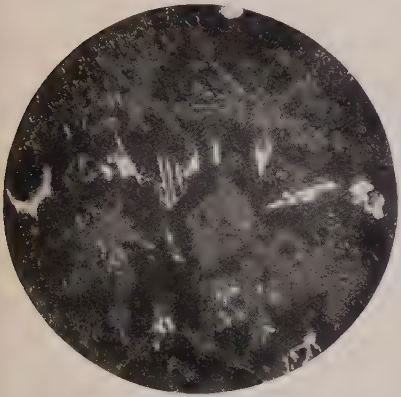

FIG. C. BTG Metal as cast. (Small ingot.)

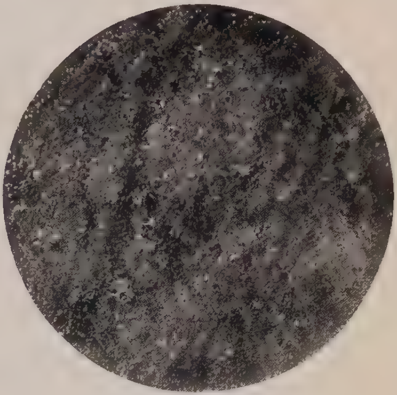

FIG. D. BTG Metal, forged. (Small ingot.)

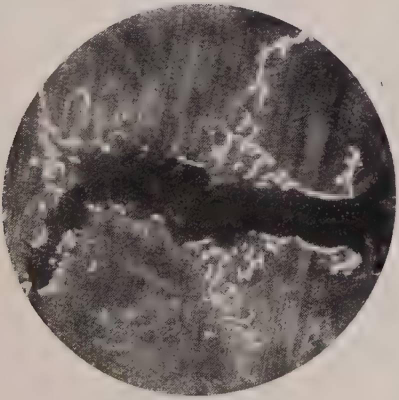

FIG. E. BTG Metal, impact fractured. (Large ingot.)

[*To face p.* 144.

ditions, they allowed of the alloys being rapidly classified in the order of their tensile strengths at given temperatures. Further, by repeating the tests at gradually diminishing rates of speed, it became possible, approximately, to estimate the effects of static stress. As the outcome of those results, the Commentry-Fourchambault & Decazeville Company filed on December 20, 1917, with the French Patent Authorities, an application for the provisional protection of a series of but slightly oxidisable alloys, possessing a high tensile strength, without brittleness, at high temperatures.[1] The composition quoted as typical in the text of the provisional patent was as follows:

	Per Cent.
Nickel	50 to 80
Chromium	8 „ 25
Tungsten[2]	0·5 „ 8
Manganese	1 „ 5
Carbon	0·3 „ 1
Iron	by difference

Owing to the outbreak of war it was not possible to resume the experiments on the viscosity of metals at high temperatures until 1918. The object of those experiments, the technical manipulation and the method of utilising the results obtained, together with the conclusions to be drawn therefrom, were published in a note presented on October 27 to the Academy of Science.[3] The experimental method employed differed in principle but little from that described by Mr. Dickenson; it consisted in recording, photographically, in terms of the times, the viscous elongation of a wire maintained at constant temperature and carrying a load. The diagram recorded allowed of the measurement of the rate of flow, in the conditions of the experiment, that rate becoming constant shortly after loading up, and remaining so as long as the amount of deformation did not appreciably alter the diameter of the test wire. There were then plotted curves showing, for a given load, the variation in the rate of viscous flow in terms of the temperatures, each of those curves marking, with considerable accuracy, the ranges of temperature within which the metal remained practically rigid under constant load.

Those tests of viscosity were practically directed towards the solution of two industrial problems: (1) to determine the conditions of annealing which would remove the internal stresses in an ordinary or a special steel, either stress hardened or quenched, and (2) to ascertain the viscous properties of alloys with high tensile strengths at high temperatures, as indicated by the tensile tests themselves.

The note published in 1919 dealt only with the first problem, and as yet no details relating to the second had been published.[1] At the Autumn Meeting of the Iron and Steel Institute in Paris, Mr. Guillet, however, made a reference to those investigations.[2] In the course of the discussion of Mr. Dupuy's paper[3] he referred to the experiments carried out at Imphy, and to the production, at those works, of iron-nickel-chromium-tungsten alloys possessing remarkable tensile properties when heated, and hinted that, as the tensile tests at high temperatures could at best only afford relative results, it had been necessary to carry out experiments on viscosity, the principle of which he outlined.[4] Those experiments had confirmed the selection of alloys having high tensile strengths when heated, and had also shown exactly how such alloys behaved in respect of static stress at high temperatures.

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[1] The date of the patent granted was August 20, 1919, No. 496929.

[2] A proportion of the tungsten is replaceable by a corresponding proportion of molybdenum.

[3] P. Chevenard, "On the Viscosity of Steels at High Temperatures," *Comptes Rendus*, vol. 169, p. 712.

Dr. Cecil H. Desch (Sheffield) wrote that Mr. Dickenson's work was of the very greatest importance for an understanding of the properties of metals at high temperatures. It was clear that the behaviour of a metal exposed to stress for prolonged periods at temperatures at or near to a red heat could not be predicted from tensile tests occupying only a few minutes. There was no reason why the extension-time curves of different materials should not cross one another, so that a comparison of tests made with short loading and with prolonged exposure to stress might place the materials in a different order of resistance. It was to be hoped that the present series would be extended to other metals, and also to include different loads. It had been shown[5] that the viscous flow of steel wires at temperatures from 575° to 725° increased very rapidly with increasing load. Those experiments were only continued over a few hours, and the form of the curves would be likely to change when determined over very long periods of time. Trouton and others had shown that the extension of a loaded specimen of metal was made up of three parts, one of which was purely elastic and practically instantaneous, another plastic and requiring time for its accomplishment, while the third was viscous. The plastic portion of the flow had been investigated in the case of many wires of metal over a wide range of temperature, but it was very uncertain how large a part it might play in those prolonged experiments. Plastic flow might be attributed to slipping along crystal planes, and in such long periods it might well be that some recrystallisation would occur, in which case plastic flow could continue throughout the experiment, although probably in small amount as compared with the viscous portion of the flow. That question might be examined with advantage. The characteristic of viscous flow was its exponential character, the elongation increasing according to a compound interest law. He (Professor Desch) had endeavoured to test some of Mr. Dickenson's curves in order to see how far they conformed to such a law. Modifying a formula given by Andrade,[1] the viscous flow might be written $l = l_0 e^{kt}$, where l was the length of the specimen at any time, l_0 the length after elastic and plastic flow had occurred, but without any viscous elongation, e the base of the Napierian logarithms, t the time, and k a constant, to be determined by experiment. The formula might be written $\log l - \log l_0 = kt$. The main difficulty in applying a quantitative test was that of knowing the length of the specimen under stress. Only a portion of the total length enclosed in the heating furnace was at the temperature observed, and the cooler parts were undergoing comparatively little extension. However, that did not affect the plotting of the logarithms of the observed extensions against time. On testing that, using the data of Fig. 7 and drawing a smooth curve through the points for 550° to 600°, one did not obtain a straight line. The extension increased too rapidly, so that the curve became steeper and steeper as time went on. That indicated that the logarithm of the extension increased as some power of the time greater than l. On plotting against the square of the time, an almost straight line was obtained. That would point to the flow not being simply viscous, some more complex phenomenon being involved. The fact that the logarithm of the time was closely proportional to the temperature at which stress was applied, brought out in Fig. 11, was of much interest, in view of similar relations found in the case of other physical properties. It would seem that the subject afforded a large field for research.

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[1] Since writing the above communication a summary of the investigations carried out at Imphy on alloys when heated has been communicated to the Academy of Science by the author, the title being "Alloys of Nickel which preserve their Rigidity within an extended Temperature Range," *Comptes Rendus*, vol. 175, p. 486.

[2] *Journal of the Iron and Steel Institute*, 1921, No. II. p. 113.

[3] *Ibid.*, p. 91.

[4] A few months later Dr. Guillet referred afresh to these experiments in greater detail in the course of a meeting of the Society of Civil Engineers of France (May 26, 1922).

[5] P. Chevenard, *Comptes Rendus*, 1919, vol. 169, p. 712.

Professor H. Le Chatelier (Member of Council) wrote that, having from the outset followed the investigations of Mr. Claude relative to the synthesis of ammonia at extremely high pressures, he had read Mr. Dickenson's paper with considerable interest, and was in a position to give an account of the Claude investigations, which had led to the use of metal possessing very high tensile strength when heated, and great chemical inertness. Mr. Claude had begun his experiments with a mild steel tube under a pressure of a thousand atmospheres, water-cooled and heated internally by a helix, through which was passed an electric current. He (Professor Le Chatelier) had made the suggestion that as iron possessed considerable tensile strength at 400° it would be sufficient for the purpose to plunge the tube into a bath of lead and thus reduce considerably the consumption of electric energy. From the first the experiment succeeded, and Mr. Claude was able to obtain from the outlet of his tube liquid ammonia, the problem being thus apparently solved. Unfortunately, after a run of six hours the plant exploded. A microscopic examination of a section of the tube showed that the metal had undergone alteration to a depth of 5 millimetres; the ferrite grains having become separated as shown in Fig. A (Plate VIIA.). The question was, what had caused that alteration?—was it the result of the chemical action of the ammonia, or of the nitrogen, or of the hydrogen? Experiments made under the same pressure of a thousand atmospheres and at a temperature of 600° on iron wires, showed that the nitrogen had no action, but that the hydrogen caused rapid alteration in the metal, similar to that observed in the case of the tube referred to above. It was necessary, therefore, to find a metal which would resist the action of the hydrogen, and he (Professor Le Chatelier) had recommended the employment of a nickel-chromium steel, the chromium being intended to raise the tensile strength of the heated metal, and the nickel to diminish its susceptibility to alteration by hydrogen. Mr. Claude applied to the Imphy Steelworks, which had already supplied Mr. Guillaume with all the material necessary for his investigations on nickel steels. Mr. Chevenard, the Superintendent of the Laboratory of those works, suggested, in the first instance, a steel having a composition similar to that of high-speed steel, mark ATG (*Acier pour Turbines à Gaz*). That steel underwent without difficulty a pressure of a thousand atmospheres at 600°. It was no longer necessary to resort to internal heating; the heat evolved by the reaction was sufficient to a great extent to maintain a temperature of 600° at the point where the external cooling was not too great. Once again it was assumed that a final solution of the problem had been found, but after a hundred hours of working the tube again exploded. A metallurgical examination showed very deep-seated alteration, although localised in a number of tiny channels which appeared to follow the boundaries of the grains (see Fig. B).

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[1] E. N. da C. Andrade, *Proceedings of the Royal Society*, 1914, vol. 90, A, p. 329.

Mr. Chevenard then suggested the use of another steel (mark BTG) having the following composition:

	Per Cent.
Nickel	60
Iron	25
Chromium	12
Manganese	2
Carbon	0·5

The Vikro studied by Mr. Dickenson was a practically similar metal. The earlier ingots, which were cast quite small, exhibited the structure shown in Fig. C, in which the white portions were a double carbide of iron and chromium.

After forging, the section perpendicular to the axis of elongation exhibited the structure shown in Fig. D, which was very fine and homogeneous. The tubes prepared from that metal yielded excellent service, and tubes of larger dimensions were therefore ordered, capable of being employed in normal manufacture. It was found impossible to forge the large ingots, and necessary to employ the metal as cast. The tubes behaved, nevertheless, very well in service, and some of them had already been in use for five thousand hours. The manufacture of ammonia by the Claude process was thus brought successfully to an issue, although the solution of the problem could not be considered as being thoroughly satisfactory. The metal, as cast, did not offer the same guarantees as forged metal. Certain tubes manufactured by that method possessed a degree of piping which rendered them unusable; one tube burst in the cold during the hydraulic tests, &c. An important step would have been made when it became possible to forge such large ingots.

An examination of the molten metal immediately revealed the reasons for the difficulty in forging and for the accidental fractures. In the large ingots the double carbide of iron and chromium was not distributed in the same way as it was in the small ingots. The grains were very much larger, and the total perimeter of their outlines in the given volume of metal was less, and therefore the thickness of the carbide bands occurring in the joints was much greater. They formed a continuous network which added greatly to the brittleness of the metal. A very simple experiment showed that. A strip 2 millimetres in thickness and 20 millimetres in length was cut from one of the large ingots, polished, and etched. The polished surface was placed on two supports 15 millimetres apart, and a slight blow given on the middle of the upper surface. The bending thus produced was hardly appreciable to the naked eye. Examined under the microscope at a magnification of 250 diameters, the deformed region exhibited a flaw following along a carbide juncture as shown in Fig. E. That carbide flaked like mica during the deformation of the metal, and created within the mass a series of points of weakness. The alloy was able to withstand considerable static stresses, but the slightest deformation was followed by sudden fracture without elongation. All the tubes which burst did so without any previous deformation. Other metals which, when hot, had less resistance, such as chromium steels not containing nickel, on the other hand dilated before opening up. Considerable progress would be attained were it possible to eliminate in that alloy the formation of the continuous network of double carbide. That was a problem which metallurgists would certainly solve. The ingots might be cast in chills; experiments in that direction yielded, however, only insignificant ameliorations. A satisfactory result would almost certainly be obtained if it were possible to lower the carbon percentage from 0·5 to 0·3 per cent. That was difficult, because of the constant presence of carbon in ferro-chromiums, and even in industrial nickel, but it was not an insoluble problem. By the use of thermite, carbon-free metals could be obtained. It would be possible to reduce by thermite a mixture of natural chrome-iron ore and a nickel oxide without affecting the quartz in the ore provided the proportion of aluminium to be used was carefully adjusted.

The brittleness of the BTG alloy referred to appeared to contradict the experiments made by Mr. Dickenson, who had obtained elongations of 17 per cent. at a temperature of 600°. It should not, however, be forgotten that the elongation of the internal walls of a tube resting on a thick mass of metal took place in a manner differing totally from that of a tensile test-piece. In any case, experience showed that the breaking of those tubes, whether prepared at Imphy or at Sheffield, took place without any appreciable preliminary deformation. Those difficulties were not an obstacle to the synthetic manufacture of ammonia by the Claude process, for most of the tubes remained sound. The failures which occurred amongst some of them served only to increase the cost of the process.

Mr. Dickenson, in reply to Mr. Brearley, regretted having conveyed an impression of severity in criticising the work of previous investigators who had carried out tensile tests at high temperatures. It had not been his intention to do so. He had merely suggested that the so-called "tensile strength," as determined by the rapid pulling of a red-hot test-piece, was of little value to a designer who was concerned with the behaviour of, for example, a container under stress at high temperatures, and had insisted that certain published data, applied in that way were, in truth, apt to be misleading, which was far from saying that rapidly conducted tensile tests at high temperatures might not, in many cases, give very useful indications regarding the comparative behaviour of different materials. Several communications made to the Institute during the past few years had shown the importance of the method in studying the sequence of changes occurring in a steel as the temperature rose or fell through the critical range, or approached the liquidus. A statement, however, whether occurring in manufacturers' pamphlets, or elsewhere, to the effect that some given steel had a stated "tensile strength" of so many tons per square inch, at, say, 600° C, not only meant nothing, but might mislead an engineer.

Mr. Brearley was quite right in supposing that he (Mr. Dickenson) would not suggest that a material having an apparent strength, when rapidly loaded, of 20 tons at 650° C., was not, under any normal service conditions, of greater resistance than a steel found to have an apparent strength of only 10 tons at 650° C., when similarly tested. Those were, however, rather extreme figures. Even so it might happen that, under very different conditions of loading, the behaviour of the two materials would not be so very dissimilar, while it was clearly indicated by Fig. 11 of his (Mr. Dickenson's) paper that, with two steels more nearly alike, the result of a comparison might actually be reversed by varying the loading conditions.

Although he agreed with Mr. Brearley that some form of load-strain diagram, taken from each of the steels at high temperatures, would have formed a useful addition to the paper, he could not admit for a moment that that method would have brought out the information which it was the purpose of the investigation to obtain. An autographic load-strain diagram obtained from a tensile test-piece maintained at, say, 700° C., and steadily, but fairly rapidly, loaded, did most decidedly indicate that failure would occur in time at far less load than the maximum actually reached in the course of the test, but such diagrams, so obtained, were simply incapable of showing, even approximately, up to what temperature, under some given stress, the material might be expected to endure for long periods without suffering prejudicial deformation.

Mr. Brearley quite correctly observed that the interest of most members in the properties of steels at high temperatures was confined to the relative difficulty or ease with which they could be deformed under rolls or hammers, but he (Mr. Dickenson) hoped that the data given would be helpful in connection with the problems of the forge and mill, although that was not the original purpose of the investigation.

He was exceedingly interested in the hot-twisted samples produced by Mr. Brearley, and had confessed, at the meeting, his inability to explain their truly remarkable behaviour. Since then he had made a few tests of a similar character, but probably with some difference in the conditions, since he had been unable to obtain Mr. Brearley's results. He (Mr. Dickenson) had passed a length of nickel steel, rolled to $\frac{5}{16}$ inch by $\frac{3}{16}$ inch, through a silica tube, wound with nichrome wire so as to obtain a high temperature (about 1000° C.) at one end, tapering down to a very much lower temperature (about 600° C.) at the other end. The rod was firmly fixed in a clamp at one end, and at the other in the chuck of a breast drill, which had been fastened in a vice so that the bar could be truly twisted, without wobbling or bending, on turning the handle. Several tests made in that way had each shown the shortest pitch at the hottest place, the pitch gradually and uninterruptedly lengthening towards the cold end, without the least evidence of the peculiar feature noticed by Mr. Brearley. The same result was obtained whether the hot end of the furnace were towards, or away, from the end in the drill chuck. At the present moment he scarcely knew whether to feel more surprised at his inability to secure, under what seemed to be quite good experimental conditions, the same result as Mr. Brearley, to whose statements of fact the greatest possible respect should always be accorded, or at the apparently freak nature of Mr. Brearley's twisted specimens. Possibly the manner in which Mr. Brearley had heated the bar and applied the brace played some part in the matter, but it was hoped to settle that point in the future.

In discussing the scaling of steels, Mr. Whiteley was apparently inclined to think that the results obtained by the author had led to better curves than the experimental methods deserved. That might be so, but in actual fact the temperatures were maintained very uniformly in the middle of the ranges stated for each collection, while the rotation of each specimen round the furnace floor, during the progress of the trial, should have gone very far towards eliminating possible errors due to temperature variations and air currents in the furnace. That the precautions taken were reasonably effective was evidenced by the curves. No scale was observed to fall from any sample during heating, but in any case the loss of weight was observed by weighing the specimen after removal of the scale. The scale upon the samples as removed from the surface always appeared to be perfectly intact, although in many cases it had lifted a little, almost certainly during the cooling of the specimen. The peculiar nature of the scale formed on nickel steels might cause divergencies from the true results, but he (Mr. Dickenson) saw no way of avoiding that, and it was not considered that any serious error was likely to have arisen from that cause, except, possibly, in the case of the 25 per cent. nickel steel which, accordingly, was not given a place in Fig. 19.

In reply to Mr. Whiteley's question regarding the rate of oxidation as the scale increased in thickness, he would simply say that a sample heated at 900° C. for a total time of 100 hours, made up of twenty separate heatings of five hours each, the scale being removed after each heating, would be found to lose far more weight by oxidation than another specimen heated for one single period of 100 hours at the same temperature. That had been confirmed in a number of independent experiments, and it was partly because of that that he had divided the total period of 100 hours into eighteen short periods so that the scale should not vary greatly in thickness during the progress of the trial. Mr. Whiteley's remarks on the process by which oxygen reached the metal through the layer of oxide were of importance, and indicated the necessity for further investigation of a subject which had, so far, received remarkably little attention.

The account given by Mr. Chevenard of researches, carried out in France, on steel alloys possessing great tenacity at high temperatures, was of considerable interest. It had, of course, long been known that nickel chromium alloys in the form of wire possessed not only very considerable electrical resistance, but also had great resistance to oxidation and deformation under stress, at high temperatures. None the less it was only during the past few years that such alloys had received any considerable application in general and chemical engineering construction, although their great usefulness was now widely recognised.

He (Mr. Dickenson) was glad that reference had been made to Mr. Chevenard's valuable note on the viscosity of steel wires at elevated temperatures, and looked forward to the publication of the results of his further investigations in the same direction.

It was to be hoped, however, that Mr. Chevenard would be able, in his further communication, to describe his experimental arrangements in more detail. He (Mr. Dickenson) would observe that wire, or even a rod of very small diameter was not a very suitable form of test-piece for comparing the behaviour of steels or alloys, used in relatively large masses, while Mr. Chevenard's tests were of very short duration, of the order of two or three hours. Mr. Chevenard appeared to consider the flow at a red heat as entirely viscous, but with present knowledge it was impossible to ignore the possibility of some continuous plastic flow.

Professor Le Chatelier gave an account, which was of special interest, of the early difficulties experienced in supplying metal suitable for use in the catalyst tubes used by Mr. Claude for the synthesis of ammonia at extremely high pressures. As Professor Le Chatelier was no doubt aware, the catalyst tubes mentioned on p. 108 of his (Mr. Dickenson's) paper were produced in Sheffield, by the firm with which he was connected, for use in the Claude process, and had successfully met the very severe working conditions necessary for the operation of that process. Although an account of the manufacturing difficulties encountered in the production of such tubes, and the manner in which such difficulties were solved, was considered to be outside the scope of the paper, he was particularly pleased to have that aspect of the matter brought out by Professor Le Chatelier. In saying that an important step would have been made when it became possible to forge large ingots of that type of nickel-chromium alloy, Professor Le Chatelier exactly expressed his (Mr. Dickenson's) own opinion, but unfortunately it was very largely those qualities which made the alloy of such special service under stress at high temperatures, which tended also to make the successful forging of large masses of the metal an extremely difficult matter. Small ingots could be forged or rolled, certainly not easily, but with no very special difficulty, but several attempts, with which he (Mr. Dickenson) had been concerned, to forge or press ingots upwards of 1 ton in weight, had been somewhat costly failures. The network of the double carbide of iron and chromium was, undoubtedly, as observed by Professor Le Chatelier, an important factor in producing the cracks which developed at an early stage in the forging operation—that was clearly brought out by Fig. 14 in the paper, as well as by Professor Le Chatelier's Fig. E—so that any method of breaking up the network, or reducing the amount of carbide present, should be of assistance. As Professor Le Chatelier remarked, that problem would certainly be solved, but in the meantime the chemical engineer had necessarily to use castings which could be made quite sound, and very reliable if the casting conditions had been properly arranged.

He was much obliged to Professor Andrew for his kind remarks. He hoped, at a later date, to continue his investigations into the scaling of steels, and proposed then to make chemical analyses of the scale formed on typical materials at various temperatures and in different atmospheres. As it appeared quite probable, from the microscopic examination so far carried out, that the layer of scale formed on a piece of steel might vary through its thickness, not only in texture but also in composition, the experimental details of the work would not be altogether without difficulty. There could be little doubt that the character of the scale formed on any given type of steel might vary both in physical characteristics and in composition, according to the nature of the furnace atmosphere, and differences in the readiness with which scale might be made to flake off were quite possibly due to that cause. The " stickiness " of the scale on nickel and nickel-chromium steels was, of course, another matter and had been explained.

He thanked Dr. Desch, not only for his present communication, but for his previous interest in the progress of the investigation. In the earlier stages of the work he (Mr. Dickenson) was principally concerned with obtaining information of a directly practical character, but, having done that, the true nature of the flow taking place in the stressed test-pieces naturally became a matter of great interest. At first it was considered that the continuous extension was due purely to viscous flow, but examination of the results showed, as was very clearly brought out by Dr. Desch, that the flow was of a more complicated character. It certainly appeared that viscous flow played a predominant part in the process of deformation, but the possibility that there was simultaneously a continuous elimination of the effects of plastic deformation at the crystal gliding planes, by some form of recrystallisation, so that plastic flow might also become continuous throughout the duration of the loading, made the problem one of great complexity, and did indeed offer a large field for further research.

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PRACTICAL NOTES ON THE MANUFACTURE AND TREATMENT OF HIGH-SPEED STEEL.

By H. K. OGILVIE (Coventry).

The following notes deal chiefly with the manufacture of high-speed steel in the basic-lined electric furnace. Although the crucible is still largely employed as a melting medium the method is of little technical interest, being entirely a melting operation as no refining is possible, and a small amount of sulphur is generally absorbed by the metal. Although this element is not quite so dangerous as in ordinary carbon steel it is nevertheless advisable to keep it under about 0·06 per cent.

The labour and fuel costs are extremely high, but the plant and overhead charges are much lower than in the case of the electric process. The cost per ton of sound billets, however, certainly is in favour of the small electric furnace, even when the latter is only working nine or ten hours per day. The steel properly made by the two methods seems to be equally good, and this is important, as the material cost is only a small proportion of the total cost of an average form tool.

Most of the crucible steel is cast into small ingots weighing up to a few cwts. each, and so long as the alloys have been completely melted there should be little segregation and few surface defects. When forged into bars for turning tools, small cutters, and drills, the structure should be fairly homogeneous and uniform throughout. It sometimes happens, however, that small particles of tungsten compound are not completely melted, particularly when tungsten powder is used. These form extremely hard spots having a Brinell hardness generally over 600 when tested with a 1-millimetre ball and a load of 30 kilogrammes, and they persist throughout the subsequent operations and may completely destroy a fine-toothed cutter working on the otherwise soft material. It is thus desirable to introduce the tungsten by means of ferro-tungsten or by the use of a tungsten-chromium alloy.

The electric furnace is commonly used for melting this class of steel, and the charge may consist entirely of high-speed steel scrap together with a small amount of turnings. The latter should be heavy and clean and are placed under the electrodes and on top of the scrap until a bath is formed. Where a large amount of tungsten steel turnings have to be used up, it is preferable to add them gradually to the charge after it has been melted, but it is very much more economical to use only good scrap, that is, heavy clean scrap with a high tungsten content, and to reject light and rusty turnings.

To attempt to make good high-speed steel from turnings alone, or where the greater part of the charge consists of turnings, is not, in this country, commercially possible. One cannot determine with accuracy the percentage of elements present, and this may necessitate the addition of large amounts of expensive alloys. If the turnings are clean and oily the carbon in the metal when melted will probably be too high: if they are rusty it will be too low with considerable loss of chromium in the slag. The latter will be saturated with oxides and must be removed from the furnace, as time cannot be spent in reducing these into the steel. Even when using heavy clean turnings which can very seldom be obtained in bulk, the loss will be at least 10 per cent. With average turnings bought from a scrap agent the loss may be 20 per cent. or more. Added to this is the difficulty of melting the turnings without breaking the circuit or damaging the bottom, together with the increased repairs necessary to the banks of the furnace. On account of the high current and electrode costs every suggestion which tends to shorten the length of each heat should be encouraged, consistent with making good steel, but in any case the time should not exceed 4½ hours for a 3 or 4 ton furnace.

When good scrap is charged the melting slag is comparatively clean and need not be removed, and the sample for analysis can be drawn as soon as the bath has been stirred up. During the next hour, while waiting for the content of carbon, tungsten, chromium, and vanadium, a heavy lime slag should be carried without getting the metal too hot. Probably a small amount of lump ferro-silicon may require to be thrown into the bath to deoxidise the steel completely, and the slag should be kept as white as possible, taking care that it is heavy enough to prevent the coal or ground electrode which is sprinkled on it from passing through into the metal. During this time most of the sulphur is removed from the steel.

The electrode coolers should fit closely enough to prevent the space between them and the electrodes acting as a chimney and drawing a stream of cold air through the furnace, having due regard at the same time to the slight variation in diameter of the electrodes themselves. With badly fitting electrode coolers, apart from the heat lost and the increased repairs necessary to the roof, the length of time required to reduce the oxides in the slag is prolonged whilst the consumption of electrode per heat is surprisingly increased. The doors should be heavy and a good fit. Double arches may be used with the best silica brick inside the furnace and ordinary fire-brick on the outside, the latter withstanding rapid charge of temperature much better. A bricklayer accustomed to this class of work can keep down the cost of repairs enormously, and will seldom interfere with the normal working of the furnace. As in every other class of melting, attention must be paid to the furnace bottom and banks after each heat, particularly at the top of the banks where siliceous material from the roof and walls tends to gather. In the case of furnaces having a bottom electrode where the bottom is often considerably weakened by iron spikes or metal to increase its conductivity, it is very important completely to remove any metal from pockets left after tapping the furnace. These should be carefully filled up with magnesite or dolomite mixed with a little basic slag and allowed to partially fuse. Where a furnace of the Heroult type is in use probably the best method of making the bottom is that employed for the basic open-hearth furnace, using oil burners if no other means of reaching the necessary temperature are available. Layers of good quality burnt dolomite mixed with a little basic slag are fritted on until half the thickness is reached. After saturating the bottom with slag and "setting back," the operation is continued, using layers of magnesite together with sufficient slag to render it just viscous at the maximum temperature obtainable until within a few inches of the necessary thickness. The top layers are completed with dolomite and slag and the furnace is finally held at a white heat for some hours by introducing coke between the electrodes.

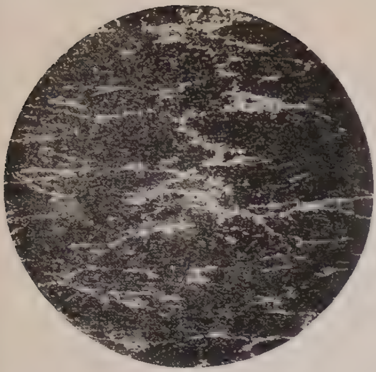
By the time the metal has been melted the percentage of carbon, tungsten, and chromium should only be slightly reduced but most of the vanadium will have been removed. The necessary amount of crushed ferro-tungsten and ferro-chromium is added as soon as the analysis is obtained, and the temperature of the steel is gradually increased. When the bath is in good condition enough ferro-manganese is thrown in to give about 0·2 per cent. manganese, and five minutes later the ferro-vanadium may be added in a bag and well rabbled under the slag. The furnace should be tapped within the next ten minutes if the samples are quiet and the temperature sufficiently high, and no additions of aluminium or any deoxidising compounds should be made to the ladle or moulds. Occasionally at this stage when getting the metal hot enough to tap, the steel, in some of the smaller furnaces especially, suddenly becomes wild, and if cast will rise over the tops of the moulds even when considerable quantities of carbon, silicon, manganese, and vanadium are present. It is useless to attempt to deoxidise the steel with additions of ferro-silicon, &c., and the only method which has given successful results in the hands of the author is to cool the steel without any addition until after thorough rabbling samples taken at regular intervals show the metal to be sound. It may be necessary in some cases to allow cooling to proceed until the steel commences to solidify round the banks. As this gas trouble has been quite widely known for a number of years, the author is rather surprised that so little mention of it has appeared in any of the home or foreign technical publications. Why high carbon steel containing up to 1 per cent. of silicon and melted with every possible precaution should, without any visible indication, suddenly become so wild as to flow out of the test ingot requires some explanation, when the slag is apparently in good condition and practically free from oxide of iron. It is difficult to believe that the trouble is due to oxide of iron, which can scarcely exist in such large quantities in the presence of elements having a greater affinity than iron has for oxygen. Also a sample ingot, badly honeycombed, after forging and rolling, showed apparently thorough welding of the gas holes, and gave impact and bend tests equal to sound steel of similar composition. At the same time there is undoubtedly a reaction between the gases and the silicon and manganese present when the steel is sufficiently cooled with consequent slight reduction of these elements, but during the time the metal is hot and wild there is no greater oxidation of silicon, manganese, or vanadium than normally takes place with sound steel under approximately the same conditions. Also the milder the steel to be made the more liable is the trouble to occur, taking into account the slightly higher casting temperature of the low carbon steel. This may or may not be due to the fact that no carburising material is added when the melting slag is removed. While the temperature seems to be extremely important the method and rate of generating heat appears to be more so. No such trouble is met with in a furnace such as the Rennerfelt, where heating is done almost entirely by radiation, or in basic Siemens practice, where equal temperatures are attained so far as can be judged by the fluidity of the steel. The metal in the electric furnace is always hotter when the first slag requires removal than it is when ready to tap the furnace, and when a clean slag is put on and fused a small amount of ferro-silicon is sufficient to render the steel quite free from any tendency to rise in the mould. Yet as the refining proceeds and the slag becomes practically free from effective oxides, the danger of gas trouble appears to increase. In this way it is similar to overpoled electrolytic copper which, while theoretically free from oxygen, swells and evolves gases on solidifying. Although this gas trouble does not often happen with high-speed steel, attention is drawn to the fact that it is by no means unknown in arc furnaces.

It is important to remember that this class of steel oxidises in the sample spoon more quickly than carbon steel, and allowance should be made for this when judging the temperature of the metal. No instrument gives very consistent results in practice when attempting to measure the temperature of molten steel, but it is very seldom that the usual pouring and film tests when carried out under the same conditions each time fail to give extremely good results. Where there is some doubt it is better to get the steel into the ladle too hot than too cold, especially if there is any device attached to the latter to regulate the speed of casting.

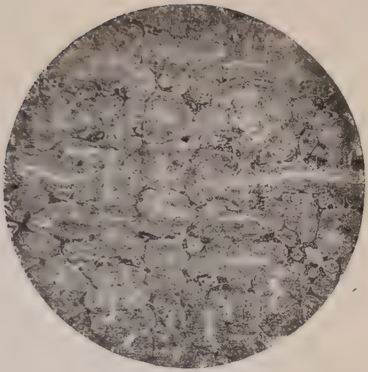
The ingots for each melt should not vary greatly in size, and octagon moulds are to be preferred. Casting should be done from the top of the mould, having the metal in the ladle hot enough to permit the slag to rise to the surface, and as small a nozzle should be used as will pour the whole heat at such a rate that lapping of the ingots is just avoided, and no crust permitted to form on the surface of the steel as it rises in the mould. This allows the ingot to solidify in the most natural manner, preventing the formation of large tungstide network and keeping the pipe down to a minimum.

Bottom pouring may improve the surface of the ingot slightly, but as the whole ingot is in the liquid state when the mould is filled with the hottest metal at the bottom, partial segregation of tungstide results, to a serious extent when the tungsten is about 16 per cent. or more, and the ingot is over 5 inches or 6 inches diameter, unless the steel is dangerously cold. The waste of metal in the trumpet and runners, and the expense and time involved in using these, does not seem to be justified, and there is also the fact that this steel is much more searching on fireclay material than any other class of steel, and it is not common to have a runner burst when the casting operation is almost completed, leaving only a shell of metal in the moulds. It is perhaps unnecessary to add that the moulds should taper slightly towards the bottom, and the head box must be a good fit. Should metal be allowed to penetrate here it is quite likely that the shoulders of the ingot will not be able to withstand the tension set up during cooling, with the result that transverse surface cracks at this point will cause a considerable loss of material.

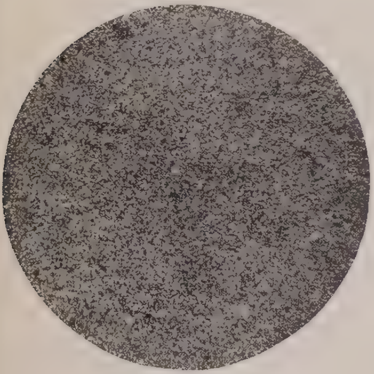
It is as well to keep the ingots under about 8 inches in diameter and 10 cwts. in weight. When it is necessary to cast both large and small ingots from the same ladle, the Batty nozzle attachment is very convenient and is also useful when the temperature of the steel has been misjudged. In any case when the ladle contains more than a ton or so of metal, one is justified in having two stopper rods, although the nozzles need not be of the same capacity. The sand used for testing the working of the rods must, however, be completely blown out of the ladle.



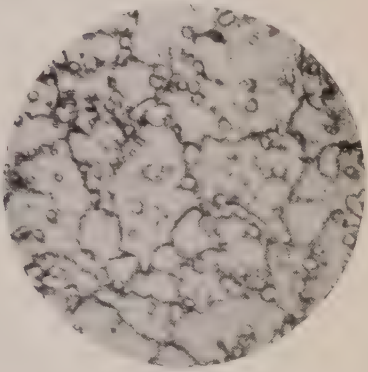
No. 1. Outside of cutter. ×60.



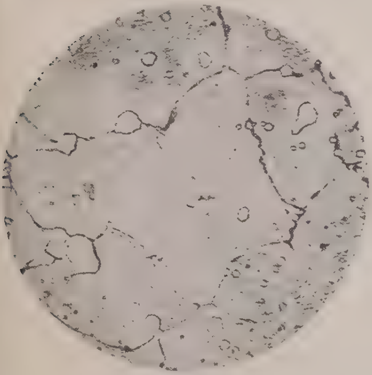
No. 2. Centre of cutter. × 60.



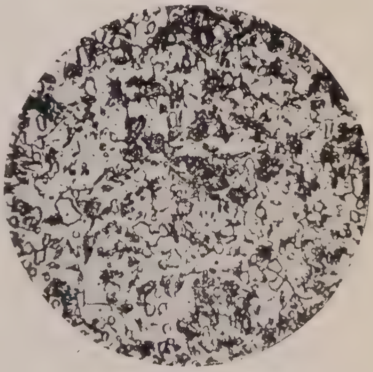
No. 3. 9″ slotting cutter. × 60.



No. 4. 5 secs. at 1300° C. × 1000.



No. 5. 35 secs. at 1300° C. × 1000.



No. 6. Just raised to 1300° C. × 1000.

[*To face p.* 160.

The ingots should not be allowed to become quite cold but should be transferred to the reheating furnace while they are still at a temperature of 200° or 300° C. So long as the ladle and moulds have been kept clean no serious surface defects should be visible, and a quick examination is all that is necessary before heating for forging. The billets, however, after cooling slowly must be very carefully examined, and any surface cracks and other flaws removed by grinding a little deeper than usually thought necessary. The care expended in this operation ought to yield a high proportion of sound rolled bars free from seams and also free from straight surface cracks which are only visible after the tool has been hardened.

It is not good practice to make fairly large thin cutters direct from forged bars unless the bore of the cutter is extremely wide. It is preferable to use a medium-sized ingot and to forge it in the usual manner to 4 inches or 5 inches round. A blank cut from this is then thoroughly forged until the required diameter is obtained. Photomicrograph No. 1 (Plate VIII.), taken at only 60 magnifications, shows the outside of an 18 per cent. tungsten steel forging which has been reduced under the press from 12 inches to 9 inches diameter. The coarse tungstide residue is only slightly broken up, while No. 2 (Plate VIII.), at the same magnifications, is from the centre of the forging and shows the original casting structure to be practically unaffected. At this power the steel correctly forged should be almost structureless, and an example is shown at No. 3 (Plate VIII.) (60 diameter) of a 9-inch slotting cutter made from an 8-inch ingot treated as above described.

Many large cutters made entirely of high-speed steel are not by any means ideally forged, yet the outside of the cutter where the teeth are machined has often a fairly good structural appearance. Towards the centre, however, it becomes gradually coarser, and on hardening, fracture is liable to take place from the keyway in spite of the largest possible radius. Should there be no keyway, the cutter very often fractures when put to work. As this coarse structure is so easily detected under the microscope, and indeed very often with the naked eye on the polished and etched steel, the steel maker has no option but to replace any fractured material where it is present, even if the direct cause of failure be due to faulty hardening. At the same time there are few things so annoying as to have an intricate and eagerly awaited batch of cutters fail in the hardening operation, after considerable time spent on machining, and it is little satisfaction to know that the material will some day be replaced.

The general hardening practice is to quench the part in oil from a temperature of 1250° C. to 1300° C., and to temper it either in an oil-bath at 220° C. or in a salt-bath at 600° C. In certain cases the tool may be hardened in an air-blast or may be allowed to cool normally in the air, depending chiefly on the size and design and whether the slight additional scaling may be disregarded.

The majority of high-speed steel tools seldom approach their breaking-down point when cutting in ordinary works practice, and for these a 14 per cent. tungsten steel with about 0·65 per cent. of carbon and 4·5 per cent. of chromium, with or without a small percentage of vanadium, gives quite satisfactory results, if hardened in oil from 1250° to 1260° C. and tempered at 220° C. Where a heavy duty cutter has to work at its maximum efficiency better results are obtained from an 18 per cent. tungsten steel having 0·6 per cent. carbon and about 4 per cent. chromium with 1 per cent. of vanadium. This is hardened in air or oil from 1300° to 1310° C. and tempered at 590° to 610° C., when it has the greatest amount of secondary hardness or capacity to resist softening, until the tips of the teeth reach a temperature of 625° C. or a little higher, the exact temperature depending on a number of factors. Laboratory tests show that by tempering at 600° C. the apparent hardness is not materially affected so long as the necessary hardening heat has been attained, while the cutting hardness is increased, the toughness or the resistance to shock, such as when the tool strikes the work, is substantially increased. Test-bars treated in this way show a toughness increase of 100 to 150 per cent. over the same steel tempered at 220° C.

Less harm is done to a fine-threaded tool by rushing it up quickly from 800° C. to 1300° C. when hardening than by soaking it for a minute or two at 1250° C. In view of the fact that some articles may show softness after tempering at 600° C., depending to some extent on the percentage of carbon and chromium in the steel, it is important to make quite certain of the exact hardening temperature. Under different lighting conditions and with different types of hardening furnaces, optical and radiation pyrometers may quite easily—and generally do—read at least 20° C. wrong, so that a carefully calibrated platinum-rhodium thermocouple suitably protected should be used in the first case, and the radiation pyrometer checked against this. Time spent on standardising the details of hardening is well repaid by obtaining more consistent cutting values.

The length of time that the steel remains at the hardening temperature is most important. No. 4 (Plate VIII.) at 1000 diameters shows the structure at the centre of a $\frac{1}{4}$ inch square bar, which had been held at 1300° C. for five seconds as near as one could judge, while No. 5 (Plate VIII.) (1000 diameters) is from a similar bar kept thirty-five seconds at 1300° C. The difference in grain size can be easily seen, and while the first bar retained a load of 130 lbs. with a deflection of 0·045 inch on 5 inches before breaking at the notch, the second bar only withstood 92 lbs., the deflection being 0·033 inch. A bar just raised to 1300° C., although not completely austenitic at the centre, withstood 142 lbs. and showed a deflection of 0·052 inch. No. 6 (Plate VIII.) is a photomicrograph of this bar also at 1000 diameters. The usual tests for hardness gave no apparent difference in these bars.

On production work where a more or less constant amount of metal is passing through the hardening furnace, it is well to have the high temperature chamber about 10° or 20° C. above the correct hardening temperature, so long as the time in this chamber is a constant for the same class of tool.

It has been found by cutting tests extending over two years that Coventry screwing dies—and this therefore applies to many other fine-threaded tools—give better results when a high tungsten steel and a high hardening temperature are used, although the secondary hardness is not taken advantage of, as the teeth do not exceed at the most a temperature of 250° C. under normal screwing conditions. Yet the resistance to abrasion is very high. One would presume that this is at least theoretically wrong, for with high tungsten a considerable number of brittle tungstide globules remain out of solution after hardening, and on the tips of the finest teeth would be liable to break away from the matrix, as sometimes happens during the polishing of the steel for microscopic examination, and thus lead to wear and possibly fracture.

The hardening of certain screwing dies, which may have as many as 68 vee threads per inch, is a most difficult operation when using the ordinary two-chamber furnace. Very little scaling is sufficient to clog up the teeth, and this scale cannot be removed by sand-blasting, or the crests of the threads are blown away. At the present time, when many firms are well equipped with projection apparatus for measuring the form of screw threads by magnifying them fifty times or more, some better method of hardening is essential failing the use of a steel capable of giving equal cutting results from a lower hardening temperature.

The difficulty has been overcome in the case of the author's firm by designing a gas-fired carborundum tube furnace for hardening these dies, with automatic feed, where the temperature of the maximum heat zone is accurately recorded and where the tool is in a slightly reducing atmosphere from the time it is introduced into the furnace until it enters the quenching bath. By this means there is no scaling whatever, and distortion troubles and also slight variations due to the personal element, which are so difficult to entirely eliminate, are kept down to a minimum or altogether avoided.

It is unfortunate that no rapid test exists for determining the actual cutting hardness of hardened high-speed steel. The file and the Brinell test are commonly used but are by no means satisfactory. Both are useful when always using a steel of very nearly the same composition hardened under standard conditions, but neither gives definite information as to the cutting properties of the tool. Both serve, however, to separate material within fairly wide limits. Cases are numerous where one method of testing gives quite a different impression than some other method. For example, a low tungsten steel (carbon, 0·65 per cent.; tungsten, 6 per cent.; chromium, 6 per cent.) hardened in oil from 1000° C. is quite easily filed, although on a section 1 inch × $\frac{1}{2}$ inch the Brinell hardness is 650. When hardened from 1300° C. it is impossible to file it, although the Brinell number is not over 550. In both cases tools treated in this way cut high carbon annealed steel of 220 to 230 Brinell almost equally well. Similarly, an 18 per cent. tungsten steel oil-hardened to give 550 Brinell will not resist wear so well as the same steel hardened and then tempered about 630° C. to give 550 Brinell.

Scratch and rebound tests seem to give anything but consistent results, and it would appear that magnetic and electrical tests have not yet been successful in solving this problem. A collection of all the known data from these tests would be valuable and might allow more work to be done in this direction.

The author is indebted to Messrs. Alfred Herbert, Ltd., Coventry, and also to Messrs. Walter Spencer & Co., Sheffield, for permission to publish a number of the details in this paper.

DISCUSSION.

Mr. C. G. Carlisle (Sheffield) said he thought Mr. Ogilvie made rather an illogical statement when he said that steel properly made by the crucible and by the electric methods seemed to be equally good. Mr. Ogilvie proceeded to say that it sometimes happened in the crucible steel process that small particles of tungsten powder had not been completely melted; obviously if it were not melted in the crucible the two processes were not equal, and seeing that the electric furnace was capable of melting tungsten powder, the electric furnace steel must be the better of the two. Mr. Ogilvie rather fell into the error of giving a specified time limit for his charges. He said " in any case " the time should not exceed 4½ hours for a 3- or 4-ton furnace." It was rather a tall order to say " in any case " in connection with an electric furnace. There were a great number and variety of occurrences that might and did happen which vitiated any calculation as to the time necessary to get the heat out. It was right to discuss the time taken when the heat had been got out, but previous to that it was much the better course to leave such prophecies alone. The metallurgical problem that Mr. Ogilvie set himself (but did not solve) was the gas trouble that he described. There was no electric furnace man who had not passed through that stage, and there was no electric furnace man who had not been exasperated by it. It was the most difficult thing he had to contend with and yet it was a phenomenon that could be understood. It was one that was capable of some fairly easy explanation, and he submitted that the conditions which Mr. Ogilvie gave were not as perfect as he supposed; he said there was gas trouble and then proceeded to say that the slag was all right. He (Mr. Carlisle) contended that the slag was not perfectly all right when the gas trouble occurred. There were two obvious reasons, and obvious reasons had to be eliminated before resort was had to abstruse physics to explain that gas trouble. First of all there was over-oxidation of the bath, which was easily possible, due to some oversight or other cause. The furnaceman might be contending with some carbon difficulty; he wanted to reduce the carbon in the bath, and by an oversight he had added too much oxygen in the form of oxide of iron, which was not boiled out and was left there at the time he raked his slag off. The trouble would persist throughout the subsequent refining, and ingots rose from that very cause. Then there was another and obvious error that crept in, and that was in the refining slag, when insufficient fusibility of the slag was obtained at an early stage, the consequence being that the electric arc played on the metal. If the slag were too limey and insufficiently fusible the direct arc would play on the bare metal, and a lumpy slag without any coating of thin slag to protect it would be produced, and fiery metal that gave trouble in the moulds would result. Mr. Ogilvie's method of cooling was one that he (Mr. Carlisle) had had to adopt on occasions and it was almost always successful. He could not understand the reaction except that it evidently threw out the oxide in solution. He was rather surprised to find that Mr. Ogilvie did not anneal his billets after forging and before he ground them. It was a favourite method in Sheffield to spoil a good deal of high-speed steel through being in too much of a hurry and grinding billets that were not annealed. A good deal of high-speed steel was spoilt during the war from that cause. If a small crack was ground without annealing the billet it simply became worse, due to the semi-hard condition of the steel after forging. The slow cooling mentioned as given after forging was seldom if ever carried out. He was rather surprised that Mr. Ogilvie forgot to anneal or temper his machine tools before hardening. He remembered a machine tool firm who were very persistent in following the usual practice of directly hardening machined tools, but finally yielded to advice and found that they were much more successful than hitherto in obtaining good tools without any danger of cracking, namely, by annealing or tempering before finally hardening.

Mr. H. Brearley (Member of Council) complimented the author of the paper on having produced a frank and straightforward contribution. That method of treatment was rarely observed in a paper dealing with tool steel. At the same time he thought the economic basis of the paper was not quite so clear. Some of the conclusions seemed extremely doubtful. He was not, however, offering any critical remarks on the paper as a maker of tool steel or the operator of an electric furnace, but rather as an interested observer of the way Coventry set out to teach Sheffield how to make tool steel, and he complimented Mr. Ogilvie on the way in which he had done it. In regard to some of the doubtful conclusions in Mr. Ogilvie's paper, allusion was made to the cost of bars or billets when the metal was melted in an electric furnace or in a crucible furnace respectively. As the kind of crucible furnace compared with the electric furnace was not disclosed, obviously the comparison was not of very much value. In Sheffield, at any rate in pre-war days, the cost of making sound bars or tool steel was pretty much the same whether the material was melted in a gas-fired crucible furnace or in an electric furnace. Of course if Mr. Ogilvie were making comparisons with coke-fired crucible furnaces he (Mr. Brearley) would not be surprised to find them in favour of the electric furnace. It was considered, or used to be in Sheffield, that the only way to put tungsten into high-speed steel or any other kind of tungsten steel, was in the form of tungsten powder. He was very glad to see that a comparatively young man from Coventry had the courage to say they should preferably use ferro-tungsten.

He was inclined to agree with Coventry on that point. He did not understand the author when he said that "to attempt to make good high-speed steel from turnings alone, or where the greater part of the charge consists of turnings, is not in this country commercially possible." He did not understand why it should not be possible in Great Britain, if it were possible elsewhere. It was stated further that one of the difficulties was that some of the turnings were greasy and would probably carburise, and that some of them were rusty and would probably oxidise the melt. He could not see why Mr. Ogilvie could not mix part of the rusty turnings with part of the greasy turnings and so level things up. There was another interesting point. Mr. Ogilvie told them about a low tungsten-chromium steel which, although it had a Brinell hardness of 650, was easily filed. In the same category was a tungsten-chromium steel with a Brinell number not over 550 which it was not possible to file. Those statements were rather startling, and as the public spirit of Mr. Ogilvie's firm was well known he would suggest that there were a number of members of the Institute who would like to have small samples of those materials in order to repeat the observations for themselves.

Mr. V. STOBIE (Dunston-on-Tyne) also referred to the point Mr. Brearley had mentioned about not making commercial high-speed steel from ordinary steel turnings. It was not possible to go on getting high-speed steel scrap with which to make high-speed steel, and some had to be made from fresh raw materials. He had had a lot of experience in that direction, and had made many 10-ton charges of high-speed steel from ordinary turnings without finding the difficulties mentioned in the paper, nor had he found anything like the melting losses Mr. Ogilvie mentioned. Mr. Ogilvie told them that they must expect anything between 10 and 20 per cent. loss on the turnings if they were going to make high-speed steel, but he did not agree that the average need be anything like that, in fact, 5 to 10 per cent. would be a very heavy allowance. It would rather look as though Mr. Ogilvie had not had the best metallurgical conditions in his electric furnace. That seemed to be proved by his stating that if he melted high-speed scrap containing vanadium most of the vanadium would have been removed by oxidation. That was totally unnecessary nowadays. He (Mr. Stobie) had plenty of instances where high-speed steel scrap had been melted containing 1 per cent. of vanadium, and over 0·8 per cent. had been left in the bath. To say that turnings could not be used and the process made commercially possible, prompted the question as to what particular experience such an opinion had been founded upon. He would suggest that Mr. Ogilvie should find out what had been done elsewhere before he turned down as uncommercial the method which, alone, could yield new material and which he (Mr. Stobie) knew to be completely successful in several steelworks in addition to his own.

CORRESPONDENCE.

Mr. J. Ferdinand Kayser (Sheffield) wrote that the manufacture of high-speed steel and the study of the phenomena associated with its cutting qualities had been carried much further than could be gathered from a perusal of Mr. Ogilvie's paper. Sheffield steel manufacturers had almost unanimously found that tungsten powder was more suitable for the manufacture of high-speed steel than ferro-tungsten. Even during the war tungsten powder seldom gave any trouble, while at the present moment ferro-tungsten often gave rise to unexplained manufacturing troubles which persisted from the forging of the ingot to the production of the finished bar. If tungsten powder and ferro-tungsten were used in the same state of division, it was impossible to detect any difference during melting, but lump ferro-tungsten was much more difficult to melt than tungsten powder, and whilst 99 per cent. tungsten was nearly always purchased in the form of a fine powder, the ferro alloys were frequently unavoidably purchased in the form of small lumps mixed with dust. Mr. Ogilvie also referred to tungsten compound which was found most frequently in tungsten powder, but it seemed to him (Mr. Kayser) that any such compound, if it existed at all, would be most probably found in ferro-tungsten.

He did not agree with Mr. Ogilvie's remarks that high-speed steel oxidised in the sample spoon more quickly than carbon steel. When a sample of liquid steel was allowed to cool in air, it first of all froze over on the surface, and then a very thin layer of oxide was formed, but such oxide was always much less in the case of high-speed steels than in that of carbon steels. High-speed steel always froze, comparatively speaking, very rapidly, and he thought the author had mistaken the first formed scum of solidified steel for oxide. Molten high-speed steel was not more searching on fireclay than any other class of steel; high manganese steels and high cobalt chromium steels were very much more searching and much more liable to break out of the moulds. With ingots of less than 15 cwt. in weight, it was a matter of indifference whether they were cast broad end up or narrow end up. He (Mr. Kayser) had had opportunities of testing that point most carefully with ingots ranging in weight from ½ cwt. to 12 cwt., and the percentage of sound material was found to be independent of the way the taper ran. It was important that there should not be much taper on a high-speed steel ingot, as too much taper was very liable to cause ingots to pull under the first few blows of the hammer. The procedure after forging, as laid down in the paper, was not the one usually adopted. Cogged bars should always be annealed before grinding out the surface defects.

He did not wish to be pedantic, but the word "hardness" was very loosely used by Mr. Ogilvie. He assumed that "cutting hardness" was used as a synonym for cutting capacity or cutting efficiency, while the term "apparent hardness" applied to the hardness of the cold sample measured by one of the recognised methods of hardness measurement.

The author also confused the terms "secondary hardness" and "capacity to resist softening." Secondary hardness was the term usually applied to the hardness measured after a previously hardened sample of high-speed steel had been reheated to some temperature below about 650° C. and then cooled out. Surely "capacity to resist softening" was the property illustrated by a curve connecting temperature with hardness? There was no connection whatever between "secondary hardness" as above defined and cutting efficiency. Reheating hardened high-speed steel to 600° C. generally increased the cutting efficiency, but did not always increase the hardness of the samples in the cold. In any cutting operations, the question whether a specified tool would cut a specified material was settled almost entirely by their relative physical properties. For instance, soft lead with a scleroscope number of 2 was cut by a lead antimony alloy with a hardness of 8. A tool with a Brinell hardness of 600 would cut another material with

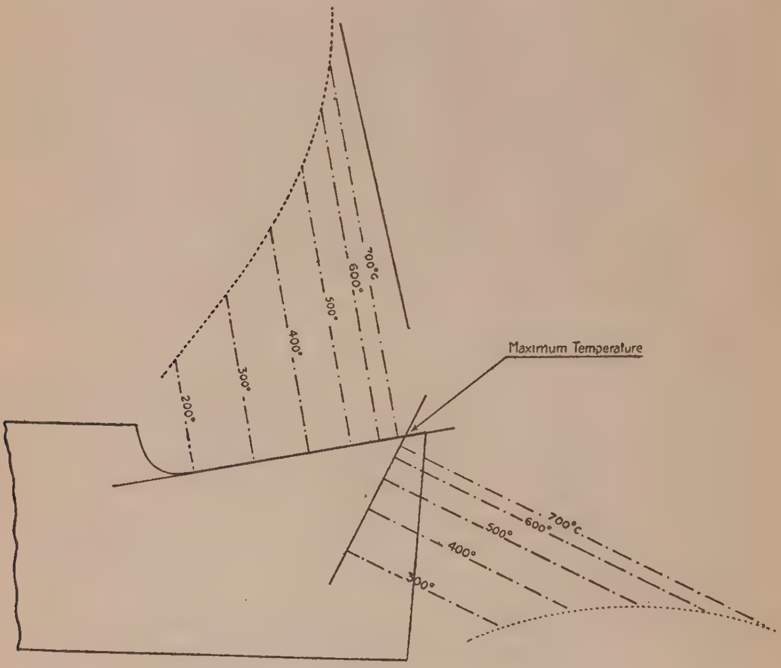


FIG. A.

a Brinell hardness of 300. During cutting operations heat was generated and caused a rise in temperature of the tool nose and also, to a certain extent, of the material being cut. That increase in temperature caused a change in the relevant relative physical properties of the tool and the work, and under the conditions so set up the ability of the tool to cut the work might be increased or decreased. Exactly which physical properties were relevant was a question which had not been definitely answered. Common sense reasoning suggested resistance to shear and abrasive hardness as two such properties. In papers read before the Sheffield Society of Metallurgists and Metallurgical Chemists and the Birmingham Metallurgical Society, he (Mr. Kayser) had published results showing an undoubted relationship between the cutting efficiency of a steel and the Brinell hardness measured at the temperatures which obtained during cutting operations. The temperatures reached during cutting had in the past been very much exaggerated. He had devoted much time and study to the determination of the temperatures of cutting tools at work, and the diagram (Fig. A) showed the results of his experiments. Some of the temperatures were determined indirectly, but the majority were actual thermocouple readings obtained from tools at work, by a thermocouple inserted in fine holes drilled through different parts of the tool nose. It should be particularly noted that the temperature of the extreme cutting edge of the tool was much below a red heat.

Mr. Ogilvie, in reply, thanked Mr. Carlisle for his criticism and particularly for his remarks on gas trouble. Steel properly made by the crucible and by the electric methods gave equally good tools, but Mr. Carlisle would agree that crucible steel containing undissolved tungsten powder had not been properly made, nor would one say that electric furnace steel containing blowholes or more than the usual amount of slag was of good quality. The time of 4½ hours for the working of a charge in a medium-sized furnace was by no means excessive. If high-class steel could not be got out within that time the reason should be investigated. The persons directly concerned should be all the time aware that every fifteen minutes the steel was held in the furnace, the working costs alone increased its production by at least 10s. per ton, neglecting overhead and other charges. Mr. Carlisle had unfortunately confined his theory of gas trouble during refining to the usual text-book explanation, which might hold good for any melting operation which did not use the electric arc in contact with the metal. Had he read the paper carefully he might have observed that no oxides were added to the charge with the object of reducing any of the elements, neither was the melting slag removed. When the steel was melted and sufficiently hot to cast safely, there was not a dangerous amount of gas present and the test ingots solidified quietly. It was after that period that the trouble developed, and was more liable to occur the hotter the steel and the longer it was held in the furnace.

Mr. Carlisle would observe that neither of his explanations quite explained the difficulty, as in the first case there were present in the steel large amounts of elements to prevent serious oxidation, and the only element partly lost during melting was vanadium. Secondly, the slag was not removed, so that, although it tended to stiffen as the heat progressed and the ferrous oxide was reduced, it was not possible for it to become lumpy. At the same time did not the arc play practically directly on the metal, no matter the condition of the slag, when the temperature of the steel was being increased? Certainly the slag appeared to cover the metal under the electrode; more so if there were excessive slag—which never happened unless a large amount of rusty turnings were present in the charge—but when passing a heavy current the space between the point of the electrode and the metal was filled with highly activated iron gas boiling at about 2400° C., so that for a small area at least the slag might as well not be present. That point was emphasised in a private communication from Mr. Rennerfelt, who pointed out that both oxygen and nitrogen compounds were being formed and absorbed by the steel directly under the arcs.

He (Mr. Ogilvie) hoped that some member might have analysed the gas from ingots suffering from that particular complaint, as he was not at present in a position to spend sufficient time on that very interesting problem.

The question of grinding the billets in the fully annealed or only partially softened state was of some importance. If the surface flaws were serious, Mr. Carlisle was right when he advised annealing the steel. He (Mr. Ogilvie) did not at all agree, however, with regard to annealing or normalising before hardening high-speed steel tools in general, with the idea of preventing cracks. In the case of certain fragile and irregularly shaped parts slowly heating to a temperature sufficiently high to remove machining strains and slowly cooling aided in preventing distortion during the subsequent hardening. That was much more important, however, for tools made from case-hardening steel, or steels where the structure of the metal had been influenced for the worse before hardening, or where the hardening range was very small. For example, a 1 per cent. carbon steel tool machined to give a weak section which was sometimes unavoidable in design, would be cracked every time if the correct hardening range were increased by 10° C. To anneal or temper all high-speed steel tools after machining and before hardening was, however, a waste of time. More attention should be devoted to the rate of heating and time of heating during the hardening process.

In reply to Mr. Brearley, Mr. Ogilvie wrote that he had found that the cost of sound billets made in the electric furnace, and in coke-fired and gas-fired crucible furnaces, was in favour of the first method. Where the crucibles were heated by producer-gas made in large quantities primarily for Siemens furnace melting, he believed that the crucible method would melt material as cheaply as a medium-sized electric furnace working continuously, where both plants were under the same management. He had been taken to task over the question of steel turnings, but could not withdraw any of his statements relating to their use. Mr. Brearley's suggestion of mixing greasy and rusty turnings did not work very well in practice, even when the scrap agents were obliging enough to send alternate deliveries of them. A metallurgist would require to depend chiefly on his instinct if he expected a definite composition when the mixture was melted.

The point that he (Mr. Ogilvie) particularly urged in the paper was the cheapest method of making high quality steel. He had no doubt that Mr. Stobie or any other capable user of a furnace could make perfectly good high-speed steel from turnings alone so long as he had sufficient stocks of ferro alloys. At the same time he did not envy the men who had the work of charging and melting 10 tons of turnings even if they were pressed, but without any desire to teach Mr. Stobie his own business he would confidently suggest that he should use only guaranteed high tungsten steel scrap so long as it was obtainable at the present price from engineering shops, with the necessary amount of equally good turnings, say 10 to 20 per cent., and melt, not with the intention of holding elusive elements like vanadium, but with the desire to get the heat out as quickly as possible. He would find that when all the costs of production were carefully considered, the advantages of using a high percentage of good scrap with rapid operating far outweighed the use of a large proportion of cheaper turnings of questionable composition. When the scrap was no longer obtainable or the price was prohibitive, turnings might be seriously considered with possibly the addition of tungsten ore.

In his concluding remarks Mr. Brearley pointed out the difference in hardness of the 6 per cent. tungsten steel quenched at 1000° C. and at 1300° C. and suggested that members might care to examine the specimens. He (Mr. Ogilvie) had therefore deposited at the Institute some samples which could be supplied to anyone interested.

Some of Mr. Kayser's remarks were contrary to both theory and practice, notably as regards the solution of crushed 75 to 80 per cent. tungsten alloyed with iron, and 99 per cent. tungsten powder in a bath of steel at 1500° or 1600° C.; the theory of the freezing of steel before oxidising; and the use of tapered moulds. High manganese steel had a greater corroding action on fireclay than tungsten steels, but the increased pressure of the heavier 18 per cent. tungsten steel was more liable to cause a defective runner to burst when the mould was nearly filled, if the speed of casting and the effect of temperature could be neglected. Mr. Kayser might be correct in his definition of the various forms of hardness, but the remainder of his criticism was more easily understood and was certainly of interest.

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Iron and Steel Institute.

THE CHANGES OF VOLUME OF STEELS DURING HEAT TREATMENT.

I. AIR HARDENING NICKEL-CHROMIUM STEELS.

By LESLIE AITCHISON, D.Met., B.Sc., A.I.C. (Birmingham), and
GEORGE REGINALD WOODVINE (Shrewsbury).

In connection with the heat treatment of steel, the alterations of volume that take place during the heating and cooling of the metal appear to be of supreme importance. It has been the intention of the authors to make some investigation of these critical volume changes, more particularly in respect of the more complex steels that are used so generally by modern engineers. The first series of tests have been carried out upon air hardening nickel-chromium steels. This kind of steel was chosen, not because of its pre-eminent importance, but mainly because one of the authors has been engaged for some time upon an investigation of the air hardening nickel-chromium steels, and particularly the changes that are produced in the mechanical properties of such steels when they are tempered at comparatively low temperatures. The physical changes undergone by air hardening nickel-chromium steels at various tempering temperatures have formed a considerable part of the investigations in question, and the volume changes really formed one branch of the work. Having gone so far it was desirable that the examination of this type of steel should be continued, and as a result the work was extended further than might otherwise have been the case.

It is felt that the results that have been obtained up to the present are of sufficient interest to warrant their publication (as an initial instalment) before the whole scheme of work has been brought to completion, and also possibly before the time is ripe for an attempt to give a complete explanation of the observed phenomena.

The type of apparatus that was employed in the experiments follows generally that used by Andrew and his co-workers and described by them before this Institute.[1] The modifications made in the apparatus were slight, and can easily be seen from the sectional diagram of the apparatus used, which is shown in Fig. 1. The most conspicuous innovation was the employment of ball joints to convey the pressure from the specimen to the lead block at one end and to the diaphragm at the other end. This precaution ensured axial and regular pressure upon the diaphragm, and obviated some difficulties that were met with when the ball was not employed.

The chemical composition of the steel employed in the experiments was as follows:

Carbon	0·33 per cent.
Silicon	0·18 ,,
Manganese	0·62 ,,
Sulphur	0·036 ,,
Phosphorus	0·038 ,,
Nickel	4·64 ,,
Chromium	1·53 ,,

The steel had been rolled to round bars, some to 1 inch and some to ¾ inch diameter.

The bulk of the experiments were made upon the ¾-inch round bars, and only a few specimens were taken from the 1-inch round bars. The original diameter of the bar made no difference to the observed results. The rate of heating employed throughout the experiments was kept as nearly constant as possible. In the different experiments the variation from the customary rate

TABLE I.

Temperature Range, °C.	Rate in °C. per Minute.	
	Heating.	Cooling.
10–100	6	½
100–200	5	2
200–300	5	3
300–400	5	3½
400–500	5	3
500–600	4	2½
600–700	3	2½
700–800	2½	2⅓

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[1] *Journal of the Iron and Steel Institute*, 1920, No. I. p. 542.

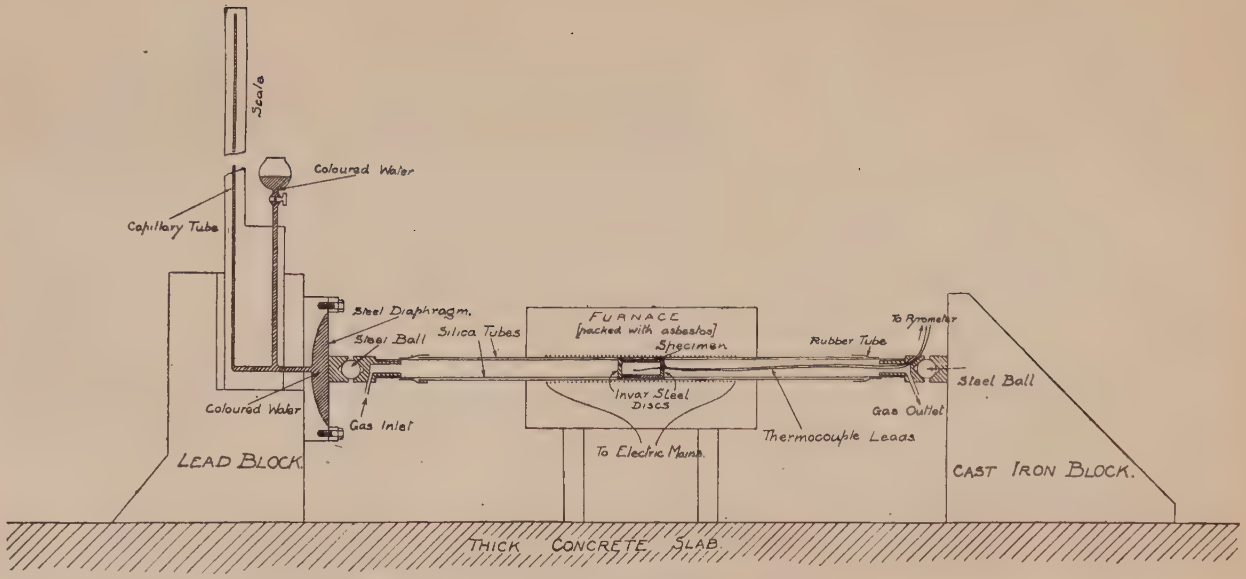
Scale
Coloured Water
Capillary Tube
Steel Diaphragm.
Steel Ball
Silica Tubes
FURNACE
[packed with asbestos]
Specimen
To Pyrometer
Rubber Tube
Steel Ball
Coloured Water
Gas Inlet
Invar Steel Discs
Gas Outlet
Thermocouple Leads
To Electric Mains.
LEAD BLOCK.
CAST IRON BLOCK.
THICK CONCRETE SLAB.

FIG. 1.—Sectional Diagram of Apparatus employed to Measure Volume Changes.

was not more than 10 per cent. either way. The general rates of heating and cooling within the various ranges of temperature between atmospheric and 800° C. are shown in Table I.

An inert atmosphere was maintained within the tube of the dilatometer during the whole heating and cooling.

The utmost care was taken to ensure that the experimental results were reliable. The observations have been repeated frequently, and wherever any possible doubt arose the experiments were repeated a sufficient number of times to ensure that the conclusion reached was accurate.

Great care has been exercised to observe and correct for the effect of changes of temperature in the atmosphere of the laboratory during the experiments. This was particularly necessary with regard to the coloured water used as an indicator in the manometer. The effect of this factor has been included in the observations set out herein, and the curves have been suitably corrected.

A considerable difficulty encountered in regard to the work upon air hardening nickel-chromium steel was the selection of a condition of the steel that could be regarded as standard, and which therefore could be used as a basis of comparison in the various experiments. It was decided eventually (at any rate for the initial series of experiments) to take as a standard condition a material that had been cooled in the air under precise conditions. Prior to any experiment, therefore, the specimen that was to be employed was heated to a temperature of 830° C. in a muffle furnace and then removed from the furnace and allowed to cool to atmospheric temperature in the air. Steps, of course, were taken to avoid oxidation. This condition, *i.e.* air cooling from 830° C., will therefore be referred to hereafter as the *standard condition* of the steel.

Experiment 1.—A specimen in the standard condition was introduced into the dilatometer, heated to a temperature of 850° C., and allowed to cool down to atmospheric temperature. The relationship between the volume and the temperature of the steel throughout the heating and cooling in the dilatometer is shown by the curve in Fig. 2. The curve shows that the steel undergoes a marked contraction during heating. The contraction commences at a temperature of 685° C. and continues to a temperature of 745° C. Heating to higher temperatures than this results in a further expansion of the steel. During the cooling of the steel no abnormal alteration of volume takes place for a considerable time. In cooling from 850° C. to 285° C. the steel contracts in the normal way. At the latter temperature an expansion commences which continues until the steel has reached a temperature of 150° C. When cooling from 150° C. to atmospheric temperature the steel contracts normally.

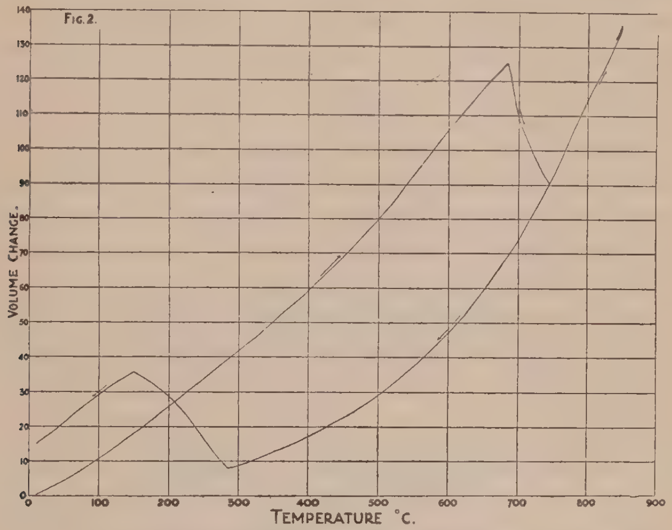

FIG. 2.—Curve showing the Volume Changes produced by Heating a Standard Specimen to 850° C.

The final volume of the steel when it has attained room temperature is, however, not the same as the volume of the steel when it was introduced into the dilatometer at the commencement of heating. The increase of volume appears to be definite in quantity.

The observations necessary to produce this fundamental curve were repeated a number of times, a specimen in the standard condition being taken initially in each instance. The form of the curve as regards the temperatures of critical expansion and critical contraction, and also the difference in the volume of the steel before and after the experiment, were practically identical in each test. The values were so nearly the same that it is impossible to show the different curves on the same diagram, as they are almost absolutely superimposed one upon the other.

As the steel in many of the succeeding experiments (after having been put into standard condition) was treated as in the above experiment, it is convenient to refer to steel that has gone through the standard treatment and then been heated in the dilatometer to 850° C., and cooled therein to atmospheric temperature, as being in the *semi-standard condition.*

Experiment 2.—The next set of experiments was carried out upon specimens that had been brought to the semi-standard condition and then were reheated in the dilatometer to various tempering temperatures, and cooled thereafter to the atmospheric temperature. Separate specimens were used for the experiments at each tempering temperature, and prior to tempering each specimen was put into the semi-standard state. The different reheating temperatures employed were 200° C., 300° C., 400° C., 500° C., and 600° C. The rates of heating and cooling were as shown in Table I.

The observations taken of the relationship between the volume and the temperature of the steel during heating and cooling to and from the different reheating temperatures are shown in Fig. 3. Attached to each tempering curve is the low temperature portion of the heating and cooling curve that corresponds to experiment 1.

The curves in Fig. 3 show that the behaviour of the steel is affected by the temperature at which it has been tempered. Tempering at 200° C. has produced a further expansion of the steel. Heating to 300° C. has produced a smaller expansion, much the same result being produced by tempering at 400° C. and 500° C. Tempering at 600° C. has resulted in the contraction of the specimen.

In Fig. 4 the relationship between the tempering temperature and the volume of the specimen after tempering at different temperatures is shown.

The different effects produced by reheating at the different tempering temperatures suggested that it would be well to investigate whether additional tempering operations at the different temperatures could bring about more complete changes in the steel. Experiments, therefore, were made by taking a steel in the semi-standard condition, heating it in the dilatometer to the selected temperature, allowing it to cool to room temperature, and then repeating the heating and cooling such a number of times as was necessary to produce in the specimen such a condition that it occupies the same volume before and after tempering.

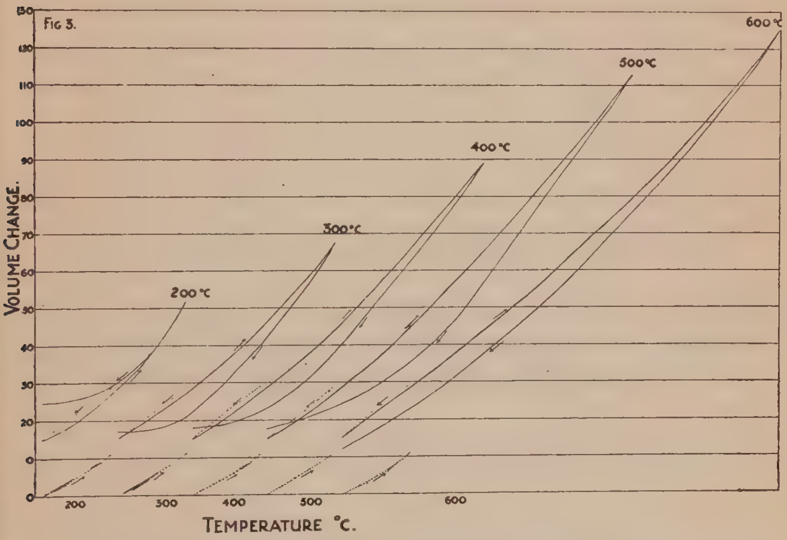

Fig. 3.—Curves showing the Volume Changes produced by Reheating a Semi-Standard Specimen to various Temperatures. The dotted curves show the bottom portions of the heating and cooling curve of the semi-standard treatment of each specimen.

Experiment 3.—The first set of observations were made upon a specimen in the semi-standard condition, reheated repeatedly to a temperature of 200° C. The resulting observations are set out in the curves in Fig. 5. The curves indicate that the number of heatings and coolings that the steel must undergo before it attains to what may be regarded as a stable volume is considerable. After the first tempering the steel does not expand any further. The second reheating brings about a contraction, though it does not bring back the steel to the volume that it occupied in the semi-standard state. The third reheating causes a further contraction, the volume of the specimen after this reheating being less than that of the semi-standard specimen. The fourth reheating brings about a still greater contraction. At the fifth reheating the volume before and after reheating is the same. The specimen was heated to 200° C. and cooled to atmospheric temperature twice more to ensure that no further contraction took place. The result therefore of the repeated heatings to 200° C. is that the steel has contracted by a definite amount.

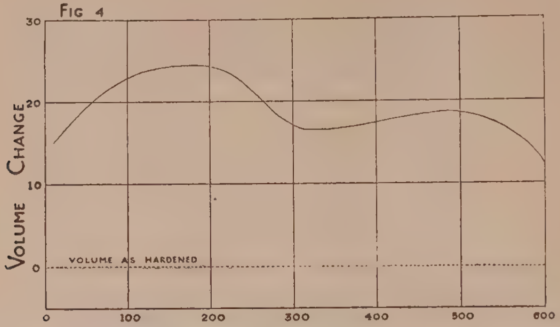

Fig. 4.—Curve depicting the Volume at Atmospheric Temperatures of Semi-Standard Specimens after Reheating once to various Temperatures.

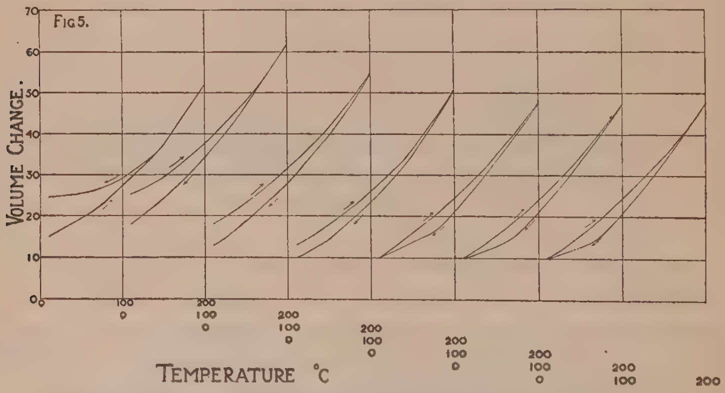

Fig. 5.—Curves showing the Volume Changes produced in a Semi-Standard Specimen by repeated Heatings to 200° C.

In Fig. 6 a curve is set out showing the volume at atmospheric temperature of the steel at different stages of the treatment.

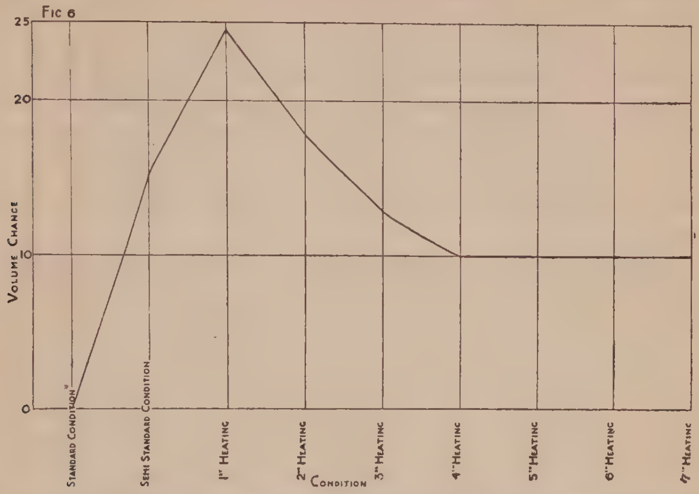

Fig. 6.—Curve showing Volume at Atmospheric Temperature of Semi-Standard Specimen after repeated Heatings to 200° C.

Experiment 4.—A similar series of experiments were then carried out with a semi-standard specimen repeatedly reheated

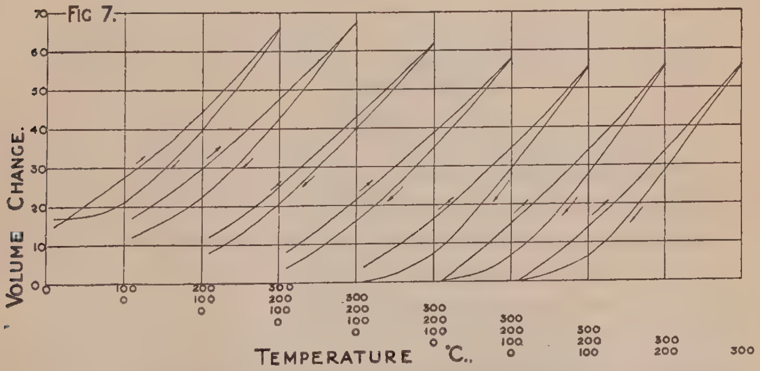

Fig. 7.—Curves showing Progress in Volume Changes produced by frequent Heatings to 300° C.

to 300° C. instead of 200° C. The resulting observations are shown in Fig. 7. Briefly, the results obtained by reheating repeatedly to 300° C. are similar to those obtained by frequent heatings to 200° C. The initial expansion of the steel is followed by a contraction, the total extent of which increases in magnitude until the sixth time of reheating. When heated to 300° C. and cooled for the sixth time the volume before and after heating is the same. The seventh reheating confirms this constant volume condition. It is to be noted, however, that the total contraction produced by repeated heating and cooling to and from 300° C. is greater than the total contraction produced by repeated heating to 200° C.

Experiment 5.—The next set of tests were made on a specimen heated frequently to 400° C. The observations are set out in Fig. 8. The general tendency of the curves is similar to those obtained from the steel by reheating it to 300° C. The constant volume condition is again attained after the sixth heating, whilst the total contraction produced by repeated heatings and coolings at 400° C. is the same in amount as that produced by repeatedly heating and cooling to and from 300° C.

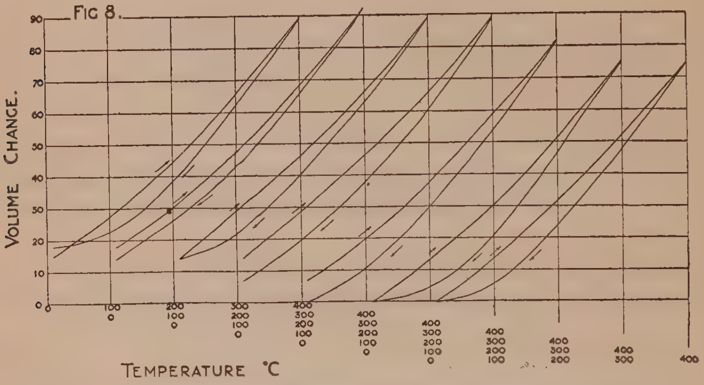

FIG. 8.—Curves showing progressive Volume Changes produced by frequent Heatings to 400° C.

Experiment 6.—The specimen heated to 500° C. expanded at the first heating and again at the second heating (Fig. 9). After the third heating the volume before and after heating was the same. During the fourth and fifth and sixth heatings and coolings the specimen contracted, whilst the seventh heating and cooling appeared to have brought about the stable condition.

FIG. 9.

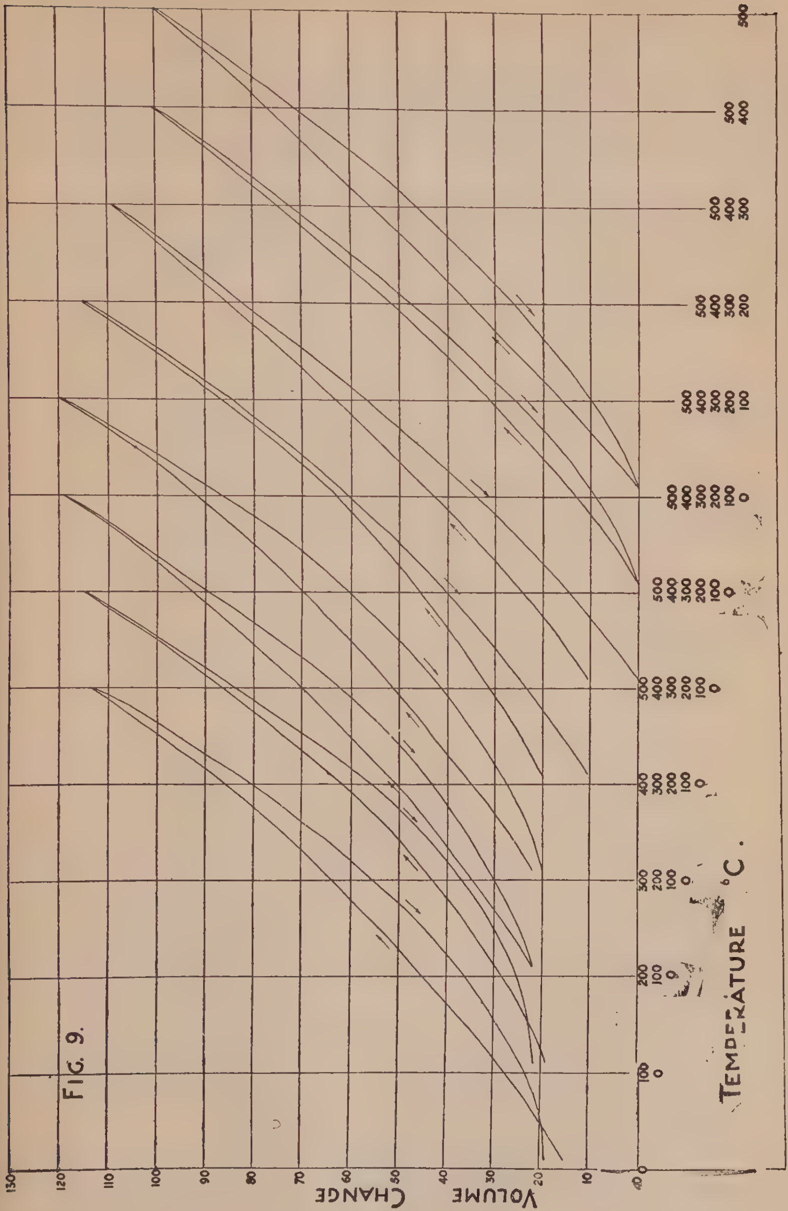

FIG. 9.—Curves showing the Volume Changes produced by repeated Heatings of a Semi-Standard Specimen to 500° C.

This was confirmed by the eighth heating and cooling. Once again the total contraction produced by the repeated heatings shows that the difference in volume between the steel in the semi-standard condition and after frequent reheatings at 500° C. is the same as the corresponding difference between the specimen heated frequently to 300° C. and the specimen reheated frequently to 400° C.

Experiment 7.—The final specimen was submitted to repeated heatings to 600° C. It was shown previously that on the first reheating to this temperature the specimen did not expand but contracted. A much greater contraction occurs during the second heating and cooling, whilst after the third heating and cooling the specimen has apparently attained a stable volume condition. The total contraction produced by the repeated heating to 600° C. is the same as the total contraction produced by heating repeatedly to 300° C., 400° C., and 500° C. The results of the experiment are shown in Fig. 10.

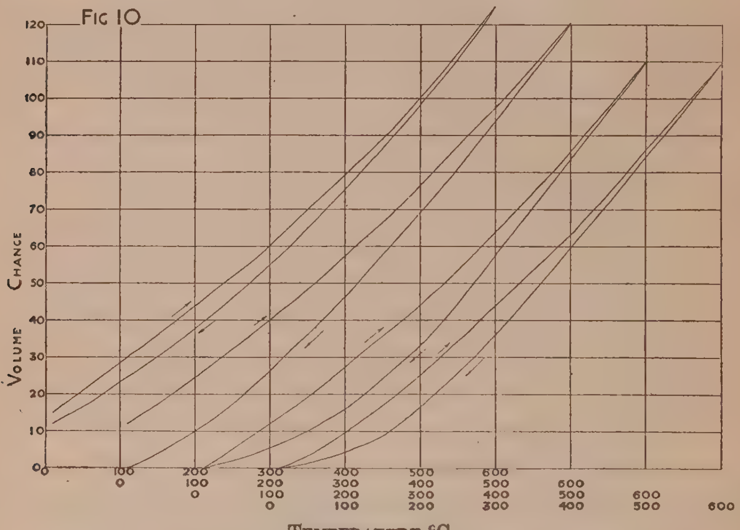

Fig. 10.—Curves showing the Volume Changes produced by repeated Heatings of a Semi-Standard Specimen to 600° C.

The experiments on the effect of reheating made it evident that reheating to a temperature as low as 200° C. was bringing about a marked change of volume in the steel. An experiment was therefore made by reheating to a lower temperature.

Experiment 8.—A specimen of the steel in the semi-standard condition was heated repeatedly to a temperature of 100° C. The results of this experiment are shown by the curves in Fig. 11, which indicate that, whilst the steel undergoes an initial expansion, this is followed by a contraction which increases in magnitude, until after the sixth heating the steel comes to what appears to be a stable volume condition. The total contraction produced by the repeated heatings to 100° C. is the same as that produced by the repeated heatings to 200° C., the total change of volume brought about by heating at either of these two temperatures being less than that produced by heating to 300° C., 400° C., 500° C., or 600° C.

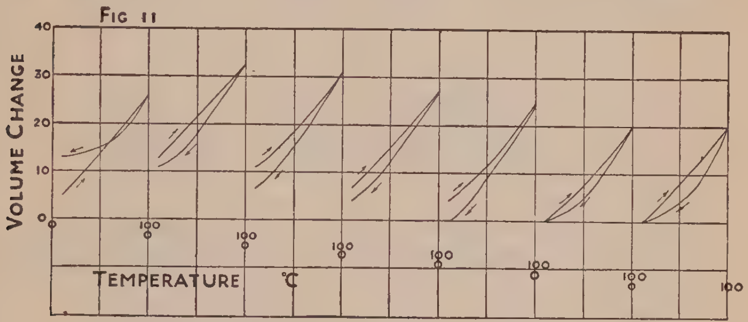

Fig. 11.—Curves showing the Volume Changes produced by repeated Heatings of a Semi-Standard Specimen to 100° C.

It is clearly suggested by the above experiments that the alterations in volume produced by frequent reheatings and subsequent coolings are additive, and might be brought about in one operation if sufficient time at the reheating temperature was allowed. Specimens, therefore, were reheated to different temperatures and maintained at that temperature for a considerable period.

Experiment 9.—A specimen in the semi-standard condition was heated to a temperature of 200° C. and maintained at that temperature for six days. The resulting observations of the experiment are shown in Fig. 12. The curve demonstrates that the nett effect of the heating has been to bring about a marked contraction, the total contraction being the same as that which has been produced by repeated heatings at temperatures of 300° C., 400° C., 500° C., and 600° C., as in experiments 4 to 7.

It is greater than the total contraction brought about by repeated heatings to 200° C.

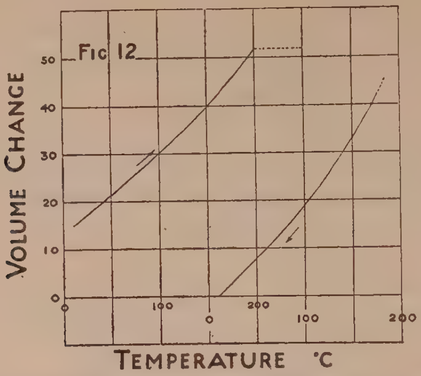

FIG. 12.—Curve showing the Change of Volume in a Semi-Standard Specimen maintained at 200° C. for a prolonged time.

Experiment 10.—A specimen in the semi-standard condition was heated to a temperature of 600° C. and maintained at that temperature for four days. It was then cooled down to the

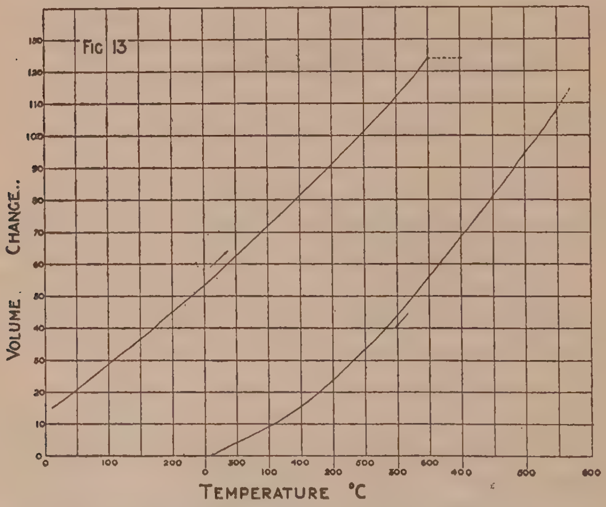

FIG. 13.—Curves showing Volume Change in Semi-Standard Specimen maintained at 600° C. for a prolonged time.

atmospheric temperature. The results of the observations made in the experiment are shown in Fig. 13. Here again, as might be expected, the total contraction produced is equal to that brought about by the repeated heatings at the higher tempering temperatures.

Experiment 11.—A specimen in the semi-standard condition was then tested at a temperature of 100° C. It was put into the dilatometer and maintained at that temperature for a week. The resulting observations are shown in Fig. 14. This curve also shows that the contraction that has been brought about by heating for a prolonged time at this low temperature is equal to that produced by repeated heatings of the steel to the higher values of tempering temperature, and that it is markedly greater than the nett contraction produced by repeated heatings and coolings to 100° C.

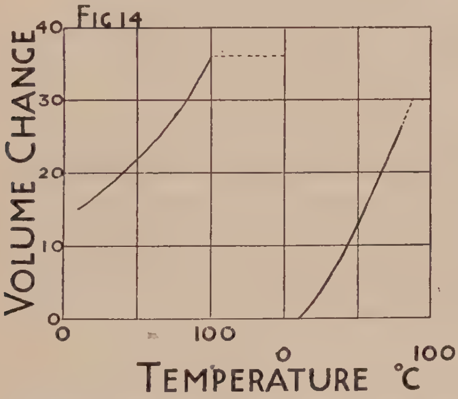

Fig. 14.—Curve showing the Volume Change produced in a Semi-Standard Specimen Heated at 100° C. for a prolonged time.

The experiments made up to the present may be summarised as demonstrating the following results :

1. That the expansion that should be produced at the critical range during the cooling from the hardening temperature is not completed during the slow cooling employed.

2. That reheating to quite low temperatures induces a further expansion.

3. That further reheating to low temperatures brings about a contraction.

4. That prolonged heating at low temperatures induces still further contraction.

5. That reheating to intermediate temperatures (300° C. to 500° C.) induces a similar initial expansion and then a contraction.

6. That reheating to 600° C. induces a contraction.

7. That the smaller initial expansion at the intermediate temperatures is likely to be the resultant of the expansion and contraction proceeding simultaneously.

8. That the total contraction brought about at temperatures up to 200° C. by repeated heating and cooling is less than that similarly produced at higher temperatures.

9. That the maximum contraction brought about in any way at all the different temperatures is the same in amount.

This work is proceeding, and it is hoped that further reports may be presented in the near future, when an explanation of the observations and their practical bearings may be attempted.

The authors are very grateful to the Directors of the Sentinel Waggon Company, Ltd., for the facilities afforded for the prosecution of the investigation.

DISCUSSION.

Mr. E. H. SANITER (Member of Council) remarked that it seemed unfortunate that the authors of the paper had used the word "volume" right through in describing their operations, when they were only dealing with longitudinal expansion and contraction. It was well known, in connection with carbon steels at any rate, that when rolled bars were frequently heated, the eventual result was a contraction in length, and it seemed to him that the whole of the results of the authors were obscured by the fact that they had only taken the longitudinal expansion and contraction, without also adding the true cubic volume, which might easily have been ascertained.

CORRESPONDENCE.

Professor J. H. ANDREW (Glasgow) wrote expressing his surprise at the methods employed by the authors in their investigation. In all comparative tests of that nature it was very necessary to select as a fundamental basis for comparison a state which might be regarded as being without any doubt normal and stable. The authors chose, however, as their standard state a steel which had been treated so as to give what could only be regarded as a metastable condition. For their semi-normal state they selected a treatment which, whilst in all probability it would give a more stable condition, appeared to be, however, quite undetermined, no curve being given to show the effect of the so-called semi-normalising treatment. Any theories or deductions built up upon such a metastable basis could not be expected to hold.

Regarding their investigation from the standpoint of the further treatment of a metastable state, there were many other points which might be criticised. It was noticed that the dilatation was given as "volumes." He (Professor Andrew) had shown some little time ago[1] that if, upon heating and cooling a simple 3·5 per cent. nickel steel, carbon 0·35 per cent., a cross sectional sample was taken, normal heating and cooling resulted in a slight expansion. If, however, a longitudinal section were taken, a marked contraction took place. There was reason to attribute that to the dendritic configuration of the steel, and to think that repeated heatings and coolings would gradually produce a condition of similarity between the two sections. The alternate expansions and contractions observed in the tempering curves shown by the authors might then be due to many things, for instance, austenite changing to martensite caused an expansion, martensite changing to pearlite a contraction, while both those reactions might take place simultaneously or separately. Then, again, the changes in length might also be due to the dendritic movement referred to. Why did the authors stop their experiments when the steel regained its so-called normal or standard state. Had they continued the heatings they would have found something of interest. If the work was but a preliminary to further work, it would be desirable that the whole should be begun again upon much sounder lines.

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[1] *Journal of the West of Scotland Iron and Steel Institute*, vol. 27, Part III., 1920–21.

Dr. Aitchison and Mr. Woodvine, in reply, thanked Mr. Saniter and Professsr Andrew for their communications. They thought the complaint raised by Mr. Saniter was justified. Whilst not necessarily admitting that the experimental results were obscured by concentrating upon the longitudinal expansion and contraction, they realised that they were really expected to deal with volumes. In future work they would endeavour to meet Mr. Saniter's point.

Professor Andrew appeared to have written his communication under some misapprehensions. The paper was confined to air hardening nickel-chromium steels, and there was no intention to give any undue prominence to that steel in the scheme of research when completed. Decisions therefore as to the best condition for testing the material that had been taken with respect to the steel dealt with did not necessarily apply to any other contemplated steels. It would be difficult in the authors' opinion to find a condition of air hardening nickel-chromium steel, at any rate in any of the forms approximating to those in which it was used commercially, which could be regarded as normal and stable. One of the objects incidental to the research was precisely to find that normal and stable condition. To adopt Professor Andrew's suggestions, therefore, would seem very much like putting the cart before the horse. With regard to the use of the word "volumes" in place of "longitudinal expansion," the authors agreed with the criticism of Professor Andrew and, as stated to Mr. Saniter, they proposed to rectify the terminology in future. They had had in hand for some time the experiments on transverse specimens suggested by Professor Andrew, and the results would be communicated later. He was, however, in error in assuming (as he appeared to do) that when the specimens after reheating and cooling came to a constant volume condition no further heatings were carried out. Actually the operations were repeated several times after the specimens had attained that state, and the fact of greatest interest which transpired from the observations was that no further volume alterations took place. Whilst, therefore, the authors would scarcely feel disposed to start all their work again, they would be very happy to have some further suggestions from Professor Andrew as to the ways in which they could profitably alter their lines of investigation.

1922, No. II.; Vol. CVI. Autumn Meeting, Sept. 5-6

Iron and Steel Institute.

A BRINELL MACHINE ATTACHMENT FOR USE WITH SMALL SPECIMENS.

BY E. D. CAMPBELL (CHEMICAL LABORATORY, UNIVERSITY OF MICHIGAN).

THE utility of knowing the Brinell hardness number of steel has been recognised for so many years that this method of testing has become almost universal. For the harder class of metals, such as steel, a standard condition of testing, using a 10-millimetre ball with a load of 3000 kilogrammes, has been generally adopted, while for soft metals the same sized ball under a load of 500 kilogrammes is used. To insure accuracy of results when working under standard conditions, the width of the test specimen should not be much, if any, less than twice the diameter of the ball, nor the thickness much less than the diameter. The scleroscope has been found quite satisfactory for testing many small specimens and thin plates or sheets. During the war some new forms of Brinell machines, adapted for use with small balls only and a very light load, intended for testing thin sheet brass, such as cartridge cases, were perfected. Special devices were required for measuring the diameters of the impressions made with these small balls, and new tables had to be computed to convert the values obtained into Brinell hardness numbers.

In the course of the researches on the constitution of steel, which have been carried on in this laboratory during the past thirty years, it has been found during the past six or seven years that small bars about 6 millimetres square and 15 centimetres long are better adapted to the facilities available, both for heat treatment and measurement of such properties as specific resistance, thermal resistivity, thermo-electromotive potential, &c., than any other size tried. Six or seven years ago a standard Alpha Brinell machine was imported and has been in regular use whenever specimens were large enough to be tested under standard conditions.

The object of the present paper is to describe an attachment for the standard Alpha Brinell machine, which attachment has been in use in this laboratory for the past two or three years and enables hardness measurements to be made on small bars with almost as much ease and accuracy as can be done on larger specimens, working under standard conditions.

In Fig. 1 are shown, in addition to the large regular balance, corresponding to a pressure of 500 kilogrammes on the ball, the light balance giving 95 kilogrammes pressure; two weights giving an additional 21 kilogrammes, and three holders for balls of 10, 5, and 2 millimetres in diameter.

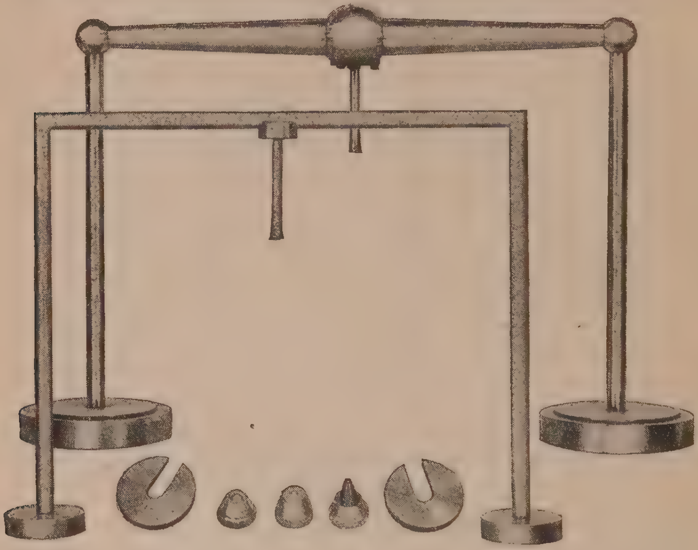

Fig. 1.—A Brinell Machine Attachment for Use with Small Specimens.

The principle involved in working out the light balance was that if a small ball—2 millimetres being adopted—were pressed into a smooth surface of given hardness and the image of the impression observed when a 16-millimetre objective is substituted for the 48-millimetre supplied with a Brinell microscope, there must be some pressure which applied to the 2-millimetre ball would give an impression which viewed through the 16-millimetre objective would appear the same size as an impression made with a 10-millimetre ball under 3000 kilogramme load on the same surface, but observed through the 48-millimetre objective.

An approximate calculation of the weight necessary for a light balance was computed from the following data. The large balance, equivalent to 500 kilogrammes, weighed 3944 grammes, or a little less than 7·9 grammes for each kilogramme pressure. When the 16-millimetre objective was substituted for the 48-millimetre, the magnification was increased 5·75 times. The pressure, therefore, which it would be necessary to apply to a 2-millimetre ball would be approximately $\frac{3000}{(5\cdot75)^2}$, or very nearly 91 kilogrammes. In order to allow for possible friction of the piston, &c., a balance was constructed out of light brass tubing, the whole weighing a little over 800 grammes, or equivalent to something over 100 kilogrammes. A piece of steel of uniform hardness and plenty large enough to use under standard conditions, was then carefully polished and duplicate impressions made with a 10-millimetre ball under 3000 kilogrammes pressure. The light balance was then substituted for the regular one and the 2-millimetre ball substituted for the 10-millimetre. An impression made with the 2-millimetre ball with the light balance was then observed through the 16-millimetre objective. The impression appeared, as was expected, a little larger than the standard observed through the 48-millimetre objective. The light balance was then removed, the weight dressed down a little, and the balance again tested as before. The light balance was thus experimentally calibrated until finally, when the weight had been reduced to an equivalent of 95 kilogrammes, the image obtained with the 2-millimetre ball under 95 kilogrammes observed through the 16-millimetre objective, exactly coincided with that obtained with the 10-millimetre ball under standard conditions. Comparisons were then made through a wide range of hardness, from that of ingot iron to freshly hardened hyper-eutectoid steels, the results obtained agreeing equally well throughout the whole range. In order to obtain close agreement, it would of course be necessary that each instrument be calibrated individually in accordance with the relative magnifying power of the objectives used. If the instrument is thus calibrated, the tables of hardness numbers computed for the 10-millimetre ball under 3000 kilogrammes may be used equally well when the hardness is measured with a 2-millimetre ball under 95 kilogrammes, but the image observed with the 16-millimetre objective.

In order to adapt the instrument to the measurement of soft metals such as are ordinarily measured with the 10-millimetre ball and 500-kilogramme pressure, the following changes were made. A carefully polished surface of pure annealed copper was used in calibrating. Duplicate impressions were made on this with a 10-millimetre ball and 500 kilogrammes and observed in the usual manner. A 5-millimetre ball was then substituted for the 10-millimetre and an impression made with the 95-kilogramme balance. When this latter impression was observed through a 32-millimetre objective, which would increase the magnification 2·20 times as compared with a 48, it appeared somewhat too small. Ordinary weights were then added to the balance, new impressions made and observed through the 32-millimetre objective until it was found that the addition of weights equivalent to 21 kilogrammes would give an impression which, when observed through a 32-millimetre objective, exactly coincided with that from a 10-millimetre ball under 500 kilogrammes and measured in the usual way. By using a 5-millimetre ball under 116-kilogrammes pressure and observing through a 32-millimetre objective, the same hardness tables, giving values for a 10-millimetre ball under 500 kilogrammes may be used.

In order to obtain the most satisfactory results when using a 2-millimetre ball with the light balance, a number of conditions should be observed. By rubbing a little heavy grease in the hemispherical depression of the holder and then pressing the ball in, the latter will have no tendency to fall out when in use. Magnetising the holder causes the ball to leave the depression and seek the edge of the holder. The surface to be tested must be polished almost the same as for metallographic work, although some very fine scratches are often useful in detecting the outline of the depression, since the pressure of the ball produces a perfect polish in the depression itself. When the surface to be tested has been polished, it should be rubbed over with a slightly oily cloth, in order to lessen the friction between the ball and the surface of the metal being tested. When making an impression the pumping up to the point where the balance rises should be done slowly and very carefully to avoid any temporary excess of pressure, and when the pressure is up to that indicated by the balance, it should be held at this point at least one and a half minutes to ensure equilibrium. On account of the small size of the impressions and the use of a 16-millimetre objective, it is necessary to use a fine adjustment in order to focus. For this purpose the tube of the Brinell microscope may be placed in an ordinary microscope stand and a mechanical stage may be used for moving the specimen until the impression is in position for focusing and reading the diameter. Strong daylight gives decidedly the most satisfactory illumination, but when this is not practicable, oblique illumination from two lamps, one on each side of the specimen, may be used.

About a year ago, in an article on " Notes as to Rates of Reaction in Certain Steels at 930° C.,"[1] the author submitted experimental evidence which showed that when bars 6 millimetres square and 15 centimetres long were quenched in cold water, the rate at which the section first entering the water passed through the critical range must have been slower than that at which the last section (No. 15) passed through the same temperature range, since there was enough difference in the concentration of the carbides remaining in solution to produce an easily measurable difference in thermo-electromotive potential at the two ends of the bar.

The Brinell hardness is largely due to a state of strain set up either by mechanical work or by heat treatment. Since the amount of this latter depends upon both the carbide concentration at the instant of quenching and the rate at which the metal passes through the critical range, it was thought that perhaps some further light might be thrown on this subject by measuring the hardness at both ends of a number of steels with widely varying carbide concentrations. Eleven steels, in the form of bars 6 millimetres square by 15 centimetres long, were selected for this work. The first six were steels which had been decarburised with hydrogen according to a method described in an article by the author on " The Decarburisation of Steel with Hydrogen."[2] The seventh was a high chromium "stainless" steel; the eighth, a special magnet steel; while the last three were straight carbon steels, differing widely in carbide concentration. In addition to the eleven steels, some bars of the commercially very pure iron known as " Armco " were used for the experiments, involving mechanical working followed by heat treatment.

The effect of mechanical work on the hardness of " Armco " iron was investigated, starting with round bars about 16-millimetres in diameter. A bar of the normal metal, as received from the mill, was drawn down cold under a hammer until reduced to a small bar a little more than 6 millimetres square. After machining to 6 millimetres square the hardness was 187.

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[1] *Journal of the Iron and Steel Institute*, 1920, No. II. p. 281.

[2] *Ibid.*, 1919, No. II. p. 407.

From another 16-millimetre round bar in the normal condition a 6-millimetre square bar was machined out with a milling machine, using a moderately heavy cut. The sides of this small bar gave a hardness of 112, while the ends gave a value of 87.

A 16-millimetre round bar was carefully annealed by packing in aluminium oxide in an electrically-heated furnace and allowing to cool with the furnace after the temperature had been raised to 928° C. From this annealed bar a 6-millimetre square bar was machined out, as in the preceding case. The hardness on the sides of the bar was 107, while that at the end was 82. This small bar was again heated in an atmosphere of pure dry nitrogen to 930° C. and again allowed to cool with the furnace. The hardness on the side of the bar was reduced by this treatment to 82. The same small bar was again heated in pure dry nitrogen to a temperature of 1040° C. and maintained at this temperature for thirty minutes and again allowed to cool with the furnace. This higher temperature of annealing in nitrogen lowered the hardness to 76.

The same small bar was returned for the third time to the electrically-heated fused silica tube furnace and heated in an atmosphere of hydrogen. The temperature was rapidly raised, the intention being to hold it at 1040° C., but it accidentally reached 1080° C. for three or four minutes before it could be lowered to 1040° C., at which latter temperature it was held for fifteen minutes, after which it was cooled very slowly with the furnace over night. This last treatment in hydrogen, which would remove all traces of dissolved oxides, lowered the Brinell hardness to 71, or only one point higher than the value obtained in this laboratory for pure electrolytic iron annealed from 958° C. The compositions of the eleven steels, together with temperatures of quenching, are shown in Table I.

As in the publication on "The Rates of Reaction in Certain Steels at 930° C.," these bars should be considered as being made up of fifteen sections, each 1 centimetre long, section 1 being the

TABLE I.

No.	Quench.	Composition, Weight per Cent.								
		C.	Mn.	P.	S.	Si.	Ni.	Cr.	W.	Fe.
1[1]	938	0·076	0·122	0·03	0·017	3·65	...	...	...	96·10
2	897	0·133	11·57	0·055	0·026	0·25	...	...	...	88·00
3[1]	938	0·036	0·677	0·038	0·020	0·231	2·80	...	...	96·2
4[1]	940	0·027	0·405	0·013	0·018	0·162	4·48	...	...	94·9
5[1]	930	0·035	0·38	0·007	0·003	0·45	...	1·40	...	97·7
6	897	0·026	0·32	0·018	0·006	0·12	...	0·24	5·04	94·2
7[1]	930	0·23	0·27	0·02	trace	0·88	...	14·32	...	84·3
8	840	0·68	0·37	0·015	...	0·29	...	0·32	5·50	92·8
9	906	0·35	0·08	0·009	0·024	0·018	...	...	...	99·3
10	910	0·76	0·22	0·016	0·041	0·169	...	...	...	98·8
11	910	1·39	0·27	0·021	0·015	0·16	...	...	...	98·1

end of the bar first touching the water and section 15 the last. The total time required for complete immersion of the bar, from the time section 1 touched, did not exceed probably one-tenth of a second, and the time required to cool from the quenching temperature to the time no colour was visible, was from four-fifths of a second to one second. The total time from the time of quenching until the bars were down to bath temperature, was from five to six seconds. After the heat treatment the ends of the small bars were carefully ground and polished. Two heavy steel blocks, which had been used as a mould, served as a holder for the small bars while the Brinell impressions were being made. The results of the Brinell measurements at the two ends of the bars and the average hardness are given in Table II.

A study of the data in Table II. shows that in the strongly hypoeutectoid steels, Nos. 3, 4, 5, 6, 7, and 9, whether nickel, chrome, or straight carbon steels, the rate of transformation of the gamma to the alpha form is so rapid that the difference in the rate of cooling between section 1 and section 15 is enough to make a measurable difference in the amount of metal trapped in the transition state, hence in the degree of strain set up. This is indicated by the greater hardness of section 15 as compared with section 1.

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[1] Indicates bars tempered at 110° C., Fe determined by difference.

TABLE II.

Steel No.	Per Cent. Carbon.	Quenching Temperature.	Brinell Hardness Number.		
			Section 1.	Section 15.	Average.
1	0·076	938	228	187	207
2	0·133	897	364	364	364
3	0·036	938	286	302	294
4	0·027	940	202	228	215
5	0·035	930	183	207	195
6	0·026	897	156	241	198
7	0·23	930	311	364	337
8	0·68	840	713	713	713
9	0·35	906	418	512	465
10	0·76	910	600	600	600
11	1·39	910	782	782	782

As has been known for many years, when manganese is atomically substituted for iron, it tends to retain the metal in the gamma or non-magnetic state. In steel No. 2, although the carbide concentration is quite low, the effect of the high manganese in suppressing the rate of transformation of the gamma to the alpha state is sufficient, so that the difference in the rate of cooling of section 1 compared with section 15 is not noticeable, the bar having the same degree of hardness at both ends.

Since the effect of increasing the carbide concentration is also to suppress the rate at which the gamma iron transforms into the alpha condition, by the time the carbide concentration approaches the eutectoid point, as in samples 8, 10, and 11, the effect of this retardation is also great enough, so that the difference in rate of cooling between sections 1 and 15 is not noticeable and the bars have the same hardness at both ends.

These hardness measurements therefore seem to confirm the conclusions concerning rates of reactions in steels at high temperatures, drawn from the previous studies on thermo-electromotive potential.

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Iron and Steel Institute.

A PRELIMINARY MAGNETIC STUDY OF SOME HEAT-TREATED CARBON STEELS.

By E. D. CAMPBELL and E. R. JOHNSON (Ann Arbor, Michigan).

One of the most comprehensive reviews of the state of knowledge in regard to dia-magnetism and para-magnetism, as well as ferro-magnetism, is given in a series of articles by Dr. Saul Dushman.[1] That the whole question, especially of ferro-magnetism, is far from being perfectly understood, will be seen from the following quotations from Dushman's introduction and conclusion :

" The subject of magnetism is thus of interest, not only from the point of view of the theoretical physicist, but also that of the electrical engineer, and it is therefore not surprising that the literature on the subject is immense. Yet there is hardly any other branch of science in which a comprehensive theory has been so conspicuously lacking as in that of magnetism. It would seem as if the very complexity of the observations that have been made has been a barrier to the establishment of a successful theory."

" When we consider the mass of observations recorded in the above chapters and compare them with the theories postulated in explanation of them, we must confess to a feeling of extreme dissatisfaction with our present views on the subject of magnetism. Here we have a field of physics at which investigators have toiled for almost a century, and what are the results ? An enormous number of disconnected facts ; a few scattered theories which attempt to correlate comparatively few observations, and a feeling of helplessness when one attempts to grasp a larger group of these facts from any single point of view."

Since the publication of Dushman's review in 1916, many articles dealing with magnetic testing of steel have appeared. These have been inspired to no small extent by the statement of C. W. Burrows,[1] that " Experimental evidence seems to point to the conclusion that there is one and only one set of mechanical characteristics corresponding to a given set of magnetic characteristics, and conversely, there is one and only one set of magnetic characteristics corresponding to a given set of mechanical characteristics."

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[1] " Theories of Magnetism," *General Electric Review*, vol. 19, pp. 351, 666, 736, 818, 1033.

The magnetic characteristics which seem to be considered most significant are the maximum induction, residual induction, and coercive force. A number of different kinds of apparatus have been perfected by means of which these magnetic characteristics might be determined easily and with high degree of precision, and most of the published papers have attempted to correlate the magnetic characteristics so determined with some of the more important physical properties, such as Brinell hardness, tensile strength, elastic limit, ductility, &c.

Among the recent papers dealing with the correlation of magnetic characteristics and physical properties is one by C. Nusbaum.[2] From systematic measurements of the maximum inductance, residual inductance, and coercive force of three steels, which were first hardened and then reheated in successive steps of 100° each, from room temperature to 950° C., it was clearly shown that for each change in chemical constitution induced by heat-treatment, there is a change in magnetic properties.

While the results of Nusbaum's experiments, as well as those of numerous other workers along similar lines, have demonstrated that changes in chemical constitution produce definite changes in magnetic properties, the object of these researches has been to attempt to correlate these changes in magnetic properties with changes in physical properties, rather than to throw any light on the probable mechanism to which magnetic phenomena are due.

One of the most extensive papers dealing with the theory of permanent magnetism which has recently appeared is that by S. Evershed.[3] Ampere's hypothesis of molecular currents and Ewing's earlier theory of interactions between magnetic molecules are used as a background for the development of Evershed's theory of the mechanism of permanent magnetism.

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[1] *Bulletin of the U.S. Bureau of Standards*, 1916, vol. 13, No. 2, p. 173.

[2] " Certain Aspects of Magnetic Analysis," *Proceedings of the American Society for Testing Materials*, 1919, vol. 19, p. 97.

[3] " Permanent Magnets in Theory and Practice," *Journal of the Institution of Electrical Engineers*, 1920, vol. 58, p. 819.

Evershed stated: "The discovery of the electron by Sir J. J. Thomson, and the evolution of a theory of the atom as a system of electrons moving with very high velocity in orbits round a centre or nucleus, have definitely turned the scales in favour of Ampere's hypothesis. The existence of the molecular current will therefore be assumed; but for mental convenience the magnetic molecule, with its complicated system of electronic currents, will be represented by an imaginary circuit or current ring, carrying a permanent and constant current, and behaving like the actual molecule so far as magnetic actions on neighbouring molecules and surrounding space are concerned."

Again, Evershed summarises the behaviour of a piece of steel under the action of a magnetising field as follows: "Looking through Ampere's microscope at what is going on inside the magnet, we have—in Maxwell's phrase—found nothing but electric circuits carrying permanent currents; nothing but a mass of current rings. We have seen that when the current rings have been oriented to an effective angle θ, the mass has a magneto-motive force equal to $4\pi si\text{N} \sin \theta$ per centimetre of length measured in the direction of orientation. In the light of Ewing's theory of the interplay of the forces of magnetic attraction which neighbouring molecules exert on each other, we next turned our attention to the different torques acting on the average current ring. In that way it was recognised that stable equilibrium of the system of current rings as a permanently magnetised or, rather, oriented mass, implied the existence of secondary torques, independent of the torque arising from the general magnetic field or induction β, which is created by the motive force $4\pi si\text{N} \sin \theta$. Now, for the creation of a secondary torque, a secondary magnetic field must be present; a field which the current rings must somehow be capable of producing. But with perfect uniformity of spacing between current rings in the mass, no secondary fields are possible; the only magnetic fields in such a system being the self-induction field of each individual ring, a field which moves with the current ring, and is therefore incapable of creating a torque, and the general magnetic field or induction β, which creates a torque $\beta si \cos \theta$. With uniform spacing, in short, there are no vacant or partially vacant regions available as local paths for a secondary magnetic flux. Hence, it was clear that secondary fields for the creation of secondary torques could only arise as the consequence of some want of uniformity in the distribution of current rings. A little consideration showed that if, in place of uniformity of spacing, the current rings were supposed to be gathered together into more or less detached and independent groups, the mutual induction of each gathering, each concentrated group, would constitute an independent secondary field, giving rise to secondary torques acting on the individual current rings belonging to the group. Here, then, is to be found that independent secondary torque which alone can provide the margin of stability in equilibrium on which permanent magnetism depends for its existence: the secondary torque which has been referred to as the group torque."

After assuming that permanent magnetism is due to the existence of a secondary torque, which in turn depends upon the non-uniformity of the distribution of current rings, Evershed continues as follows: "At the same time another inference was drawn, namely, that in coercive force we have a rough indicator of the degree of concentration into independent groups, an indicator of the strength of the bond of mutual induction by which the current rings in a group hold themselves together when in the oriented state. Without that gathering together, and without the resulting capacity to create those secondary torques by which the current rings are able to resist forces tending to destroy their orientation, coercive force would be non-existent."

Under Evershed's concept the magneto-motive potential to which permanent magnetism is due resides solely in the current rings due to electrons in the iron atoms, and the presence of carbon or other non-magnetic material serves to bring about a localised segregation or grouping of these current rings.

That marked segregation or grouping of the iron atoms containing the current rings may not necessarily be the only cause of permanent magnetism, is suggested in Evershed's further statement as follows: "Hence the gathering together of molecules of equal magnetic moment into concentrated groups need not be regarded as the sole possible mode of departure from uniformity which will endow the mass with the necessary power to form local bonds of mutual induction. Any kind of molecular variformity which, in effect, brought about an unequal distribution of the elementary magneto-motive forces, would give rise to a similar state of things. And in view of the fact that iron is found to possess an increased ability to maintain itself in a partially oriented state when carbon and other non-magnetic substances have been introduced, it seems by no means unlikely that the necessary departure from uniformity may consist in the congregation, in one mass, of equally spaced molecules possessing unequal magnetic moments ; some stronger, some weaker than the average. As a limiting case, we may imagine the presence of non-magnetic molecules distributed throughout a mass of magnetic molecules. Such an arrangement would provide magnetically vacant spaces for the propagation of local fields of mutual induction, in much the same way as the concentrated groups which we have taken as a simple example of variformity."

A very recent contribution to the theory of magnetism in iron is given by Sir J. Alfred Ewing.[1] Ewing's paper opens with the following statement : "The object of this paper is to amend, in an important particular, the theory of ferromagnetic induction put forward by me more than thirty years ago, and to describe a new model. That theory was itself a modification of the earlier theory of Weber. To Weber is due the fundamental notion that a substance contains minute particles, each of which acts as a magnet, and that in the process of magnetising a ferromagnetic substance these are turned into more or less complete alignment. The ultimate magnetic particles used to be called 'molecular magnets'; we now recognise them as attributes of the atom, not of the molecule, and (in all probability) they derive their magnetic moment from the circulation of electricity in electron orbits or in ring electrons. What turns is not the molecule nor the atom, but something within the atom."

While Evershed considers the iron atom to consist of electrons in orbital motion with the nuclei centre of the atom as the centre of rotation, Ewing, as well as many other physicists and chemists, regards the cubical arrangement of electrons as more probably representing the structure of the iron atom. Ewing says : " Take, for instance, a structure such as H. W. Hull has suggested on the basis of his X-ray analysis as a probable structure for the iron atom,[1] in which two of the electrons, on opposite sides of the nucleus, form a doublet, and the remaining twenty-four are grouped in octets further from the nucleus, along the diagonals of a cube. Think provisionally of these octets as making up fixed magnetic elements, which correspond to A, B, C, and D of the model, with axes that lie in the cube diagonals of the atom, coinciding (it may be supposed) with the trigonal axis of the crystal. They point radially inwards, and all their inner ' poles ' are of the same name. In the inner space the doublet, which corresponds to W—the Weber element of the model—turns under the influence of any impressed field. When there is no external field, the Weber element may be in any one of eight positions of stability, pointing towards one of the fixed elements, namely, towards one of the eight corners of a cube."

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[1] "The Atomic Process in Ferromagnetic Induction," *Proceedings of the Royal Society*, 1922, Series A, vol. 100, No. A706, p. 449.

Ewing's theory seems to give a very satisfactory explanation of the way in which, in pure iron, a Weber element located at the centre of eight strong but essentially equal magnetic fields will be oriented by an external field in a direction depending upon the impressing force.

Since, however, Ewing's paper deals specifically with the atomic process in ferromagnetic induction, no theory concerning the mechanism of permanent magnetism in bar magnets is given ; the nearest approach to such a theory being in the following statement : " It is at least open to conjecture that in an ideal crystal of perfectly pure and perfectly unstrained iron, what I have called the fixed magnets in each atom may be completely symmetrical and rigid in maintaining their symmetry, while the Weber element turns. In that case the mutual directing forces exerted by the Weber elements on one another, from atom to atom, might still provide the small amount of stability that is required when superposed on the far stronger but balanced forces which are due to the fixed magnets. When, however, the iron is impure or is rendered æolotropic by straining, it is natural to suppose that each atom is more or less distorted ; in any case the balance of magnetic forces within it is disturbed, and a stronger type of control, due to unequal action on the part of the fixed magnets, is brought into play."

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[1] " The Crystal Structure of Iron," *Physics Review*, 1917, vol. 9, p. 85.

The object of the present communication is to bring before the Institute some further experimental evidence in support of the hypothesis of the mechanism of permanent magnetism in bar magnets embodied in a paper submitted by the author to the Faraday Society [1] in July 1920. This hypothesis states that the force fields existing at the poles of a bar magnet represent the cumulative effect resulting from the serial alignment of the poles of the force fields of carbides or other solutes in solution.

Apparatus Used in Experimental Work.

Brinell hardness on either the sides or ends of 6-millimetre square bars was measured with the aid of a special attachment to a standard alpha Brinell machine, to be used with a 2-millimetre ball under a pressure of 95 kilos. The details of this attachment, with some results obtained with it, constitute the subject-matter of a separate paper submitted to the Institute at its present meeting.

Specific resistances were measured by means of a precision potentiometer, the bars being immersed during measurement in an oil-bath maintained by means of a thermostat at 25° C. ± 0·02°. Under the hypothesis that permanent magnetism depends upon the magneto-motive potential of the carbides, a uniform method of magnetisation, intended to systematically bring the magneto-motive potential to a maximum, was adopted. The magnetising coil used consisted of 1004 turns of wire wound over a length of 25 centimetres on a piece of brass tubing, 15 millimetres inside diameter. The 15-centimetre long bar to be magnetised was held in a cylindrical support intended to keep it in the axial centre. When the bar had been inserted to the longitudinal centre of the magnetising coil, round bars of "Armco" iron, about 14 millimetres in diameter, were inserted at both ends. These bars extended far enough beyond the end of the magnetising coil, so that they could be readily connected by means of a heavy yoke—also made of Armco iron—closing the magnetic circuit.

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[1] "A Force Field Dissociation Theory of Solution Applied to some Properties of Steel," *Transactions of the Faraday Society*, vol. 16, Part 3, p. 554.

When a bar to be magnetised was in position, a small current of about 0·2 ampere was applied by closing the switch in the magnetising circuit. The current was then increased about 0·3 ampere, after which the switch was momentarily opened and again closed ; the current being always kept in the same direction. This process of systematically increasing the current, before momentarily opening the switch and again closing, was repeated until a final current of about 2·7 amperes was reached, although from 1·3 to 1·5 amperes was all that was usually required to saturate the bars.

The force with which a disc of carefully annealed electrolytic iron was attracted by one pole of a magnetised bar at a distance of 1 centimetre was measured by means of a special balance and holder, illustrated in Fig. 1 (Plate IX.).

The balance consists of a disc (A) 15 millimetres in diameter, about 3 millimetres thick, made of pure electrolytic iron attached to a bar (B) 6 millimetres square by 15 centimetres long, also made of pure electrolytic iron. The bar passes through a knife-edge holder (C) made of Armco iron. At the farther end of the electrolytic iron bar is attached the long screw and balancing nut (D), both made of Armco iron. The electrolytic iron disc and bar, as well as the long balancing screw and nut, were very carefully annealed after the completion of all machine work, in order to completely remove any state of strain on the surface that might have been due to the action of the cutting tool. A light scale pan (E) of non-magnetic material is hung close to the end of the long balancing screw, the weights used being a number of analytical weights, increased by attaching to them weighed pieces of fine platinum or aluminium wire, so that the equivalent number of dynes could be read directly.

The pedestal on which the knife-edges rest, as well as the heavy plate serving as a base and the adjusting screw (F), are made of brass. If the brass gauge block (G), which is 1 cm. ± 0·01 mm. high, is placed on the electrolytic iron disc, the distance from the lower face of the bar to be tested can be accurately set to 1 centimetre by means of the fine adjusting screw (F). The brass base of the balance, as well as the support for the holder (H), rest on a heavy ground glass plate, in order to have a perfectly flat but not slippery surface.

The holder (H) in which the bar (I) to be tested is placed is made from a piece of brass tubing, 11·3 millimetres internal diameter, and wound with three layers, each containing 201 turns of wire, the length of the wound portion being 13·6 centimetres. The holder is wound with tape for protection and the terminals connected to a double pole, double throw switch (J), by means of which the direction of the current to the holder can be readily controlled. The steel bar under examination extends about 3 millimetres below the end of the brass tube and rests on a piece of 1 millimetre diameter brass wire, soldered to the lower end of the holder. The tube, 11·3 millimetres inside diameter, enables a 6-millimetre square bar to be used, even when quite badly warped from drastic heat-treatment. Bars can readily be kept centred in the tube by slipping over each end a small collar made by cutting off a very short piece of rubber tubing. The electrical resistance of the 603 turns of wire on the holder is 2·512 ohms, and the inductance in millihenrys as given in a certificate from the U.S. Bureau of Standards, with the pure electrolytic iron bar as core, is as follows :

0·1 amp.	18·2	0·8 amp.	19·4
0·2 „	18·7	0·9 „	19·4
0·3 „	19·2	1·0 „	19·0
0·4 „	19·4	1·1 „	18·8
0·5 „	19·4	1·2 „	18·6
0·6 „	19·4	1·3 „	18·5
0·7 „	19·4	1·4 „	18·2

The current used in the holder is taken from storage batteries, control being by means of an adjustable rheostat and standard milliameter.

Before magnetising, the ends of a bar are ground smooth and square, so that when the bar rests on the wire support at the lower end of the holder the lower end of the bar will be parallel with the electrolytic iron disc and centred over it. In order to measure the field of a pole, a bar which has had the ends properly ground and has been strongly magnetised, as described before, is placed in the holder ; the balance moved into position, so that the disc is directly under the bar and the distance between the disc and the lower face of the bar accurately adjusted by means of the gauge block (G) and the adjusting screw (F). The disc, which will at once be attracted by the magnet, is held down with one hand so that it rests on the adjusting screw, while with the other hand the balancing nut (D) is turned until it reaches a point where the disc will just barely leave its support when released. This point can be determined to within 5 to 10 dynes. When the attractive force of the magnetic field has thus been balanced by means of the balancing nut, the whole balance is moved out from under the magnet and weights placed on the pan until the system is again in balance. In this way the attractive force of the magnet may be read directly in dynes. If the north pole of the magnet is down, there is an effect due to the earth's magnetic lines of force, which in the case of fairly strong magnets will make the measured values about 40 dynes higher than they would be if there were no terrestrial magnetism, while if the south pole is down this effect is reversed. With weak magnetic fields, the effect of terrestrial magnetism is diminished.

Since results obtained must be comparative only, variations due to size and form of bars are eliminated by having all bars of substantially the same size, 6 millimetres square by 15 centimetres long. All measurements were made with the north pole down, and values are not corrected for the effect due to terrestrial magnetism.

After measuring the north magnetic field, the induced fields were successively determined by applying currents in eight steps, from 0·10 ampere to 0·80 ampere inclusive, the currents being in such direction that the induced field would be of the same polarity as that of the magnet, thus being superposed on it. While a given current was flowing the total attractive force due to the induced field, together with the permanent field, was balanced in the same manner as when measuring the permanent field alone. When this had been done, the switch was opened and weights enough put on the pan to bring the system in balance with the permanent field. From the weights required, the attractive force, due to the superposed induced field, could thus be read directly in dynes. No evidence was found indicating that superposing induced fields in this way had any effect on the permanent field of the magnet.

The capacity of the balance is about 3000 dynes, so that when it was necessary to go above this amount a rectangular U-shaped piece of brass plate was placed on the electrolytic iron bar (B) close up against the disc. The weight of this plate of brass was carefully adjusted, so that when it was in place it was equivalent to 2500 dynes on the balance pan.

After measuring the induced fields, the current required to demagnetise was determined as follows. Successive currents of opposite polarity to that of the bar were applied, beginning with 100 milliamperes, and increasing with each application by steps of the same amount. After each application, lasting a few seconds only, the attractive force of the remaining field was determined until a point was reached when the balanced lever would slowly fall back to its resting point, even when raised quite near the bar.

The attractive forces of the eight induced fields of a bar of carefully annealed pure electrolytic iron and of a bar of a hypo-eutectoid steel (number 4) in the hardness state, are given in detail in Table I. The attractive forces of the induced fields, given in Table I., are shown graphically in Fig. 2, in which the attractive forces in dynes are given as ordinates, while the abscissæ represent both the currents used and the current squared. Curve A is that of the electrolytic iron plotted with currents as abscissæ and curve A^2, the same plotted with currents squared. Curves B and B^2 are the corresponding curves for the hardened hyper-eutectoid steel.

TABLE I.

Current in Ampere.	Induced Fields in Dynes.	
	Electrolytic Iron.	Steel No. 4, Hardened.
0·10	70	50
0·20	210	95
0·30	425	155
0·40	745	205
0·50	1125	265
0·60	1585	335
0·70	2175	395
0·80	2780	465
Sum 8 fields	9115	1985

An inspection of the curves in Fig. 2 shows very clearly that the attractive force of the induced fields with electrolytic iron increases very much more rapidly than the inducing current (curve A), approaching more nearly a linear function of the current square (curve A^2). On the other hand, in case of the hypereutectoid hardened steel, while the attractive force increases somewhat more rapidly than the inducing current (curve B), it approaches more nearly a linear function of the current than it does of the current squared (curve B^2). The attractive force of the induced fields was determined for all the steels in their variously heat-treated condition, and their results tabulated and plotted in curves similar to the results in Table I. and Fig. 2. As, however, the attractive force of the induced fields was in all cases less than that of annealed electrolytic iron, but stronger than that for the highest carbon steel in the hardened state, a

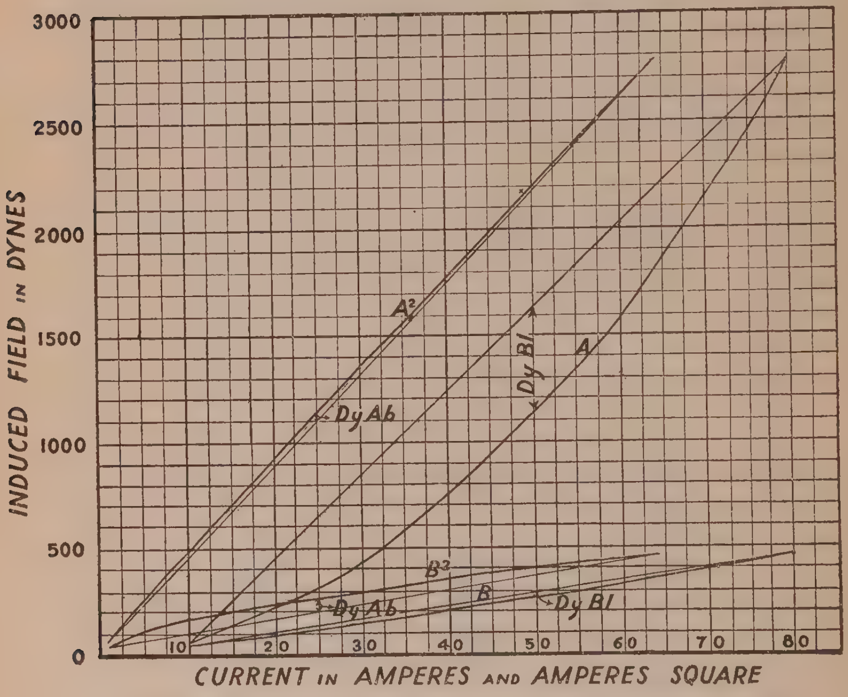


Fig. 2.—Diagram showing Attractive Forces of the Induced Field.

detailed tabulation of these measurements will be omitted. From the tabulated results, " the sum of the eight fields," as well as the induced field for 0·50 ampere, were taken. The current required to give an induced field equal in strength to that of the permanent field was read off from the plotted values. All the other measurements of the strength of the induced fields, when plotted, gave as smooth curves as those shown in Fig. 2.

In order to enable the general tendency of the curves representing the induced fields to be determined, the following system was adopted. From the curves plotted with inducing currents as abscissæ, the distance which a given curve at a current of 0·50 ampere fell below a point on a line connecting the lowest and highest values, was measured and expressed as " dynes below," as shown in Fig. 2, curves A and B. In a similar manner with the induced fields plotted with the current squared as the abscissæ, the distance which a given curve at a value of " 0·50 ampere squared " came above a line connecting the lowest and highest values, was expressed as " dynes above," as shown in Fig. 2, curves A^2 and B^2. The ratio of " dynes above " to " dynes below," in the case of the annealed electrolytic iron shown in Fig. 2, is 0·061, while that of the hardened hypereutectoid steel is 2·05. It will thus be seen that the lower the ratio the nearer the curve approaches a linear function of the " current squared " value.

Four straight carbon steels were selected for the experiments involving heat-treatment. In the paper on the force field dissociation theory of solution, as well as in a number of other papers given by one of the authors before the Faraday Society, the full recognition of the essential unity of mechanism, *i.e.*, of atomic relations between solute and solvent in steel with that of solutes and solvents in ordinary solutions, has been advocated. In ordinary aqueous solutions, a molar solution may be defined as " one which contains the molecular weight of the solute in milligrammes in 1 cubic centimetre." The volume concentration of metallic solutions of which the specific gravity, as well as the composition in weight per cent., is known, may be readily computed from the simple formula

$$\frac{10D \times \text{weight per cent.}}{\text{atomic weight}}$$

In this formula D is the specific gravity, and the atomic weight that of the element in question. The atomic concentration in milligramme atoms per centimetre cubed of the four steels used, as well as the composition in weight per cent., are given in Tables II. and III.

TABLE II.

Bar.	Concentration in Milligramme Atoms per cc.				
	C.	Mn.	P.	S.	Si.
1	2·29	0·11	0·02	0·06	0·50
2	4·94	0·31	0·04	0·10	0·46
3	6·79	0·27	0·03	0·05	0·46
4	8·97	0·38	0·05	0·04	0·44

TABLE III.

Bar.	Composition by Weight per Cent.				
	C.	Mn.	P.	S.	Si.
1	0·35	0·08	0·009	0·024	0·18
2	0·76	0·22	0·016	0·041	0·169
3	1·05	0·19	0·013	0·020	0·167
4	1·39	0·27	0·021	0·015	0·16

The nine heat-treatments of the steel bars were as follows:

1. Steel number 1 was quenched in cold water from 851° C., while numbers 2, 3, and 4 were quenched from 910° C. in water at 16° C. All bars have stood at room temperature for some months before the present set of measurements were made.

2. Steel number 1 was maintained a little below 100° C. over night, followed by six hours at 110° C. Numbers 2, 3, and 4 were maintained for seventeen hours at 110° to 114° C.

3. All four steels were heated in an oil-bath for one hour at a temperature of 200° to 203° C. and allowed to cool slowly.

4. The bars were placed in a fused silica tube in an atmosphere of hydrogen and the temperature raised and maintained at 298° C. for four hours, and then allowed to cool with the furnace.

5. The bars were placed in a fused silica tube in an atmosphere of hydrogen and maintained for thirty minutes at a temperature of 400° to 404° C., and then allowed to cool slowly with the furnace.

6. The bars were similarly placed in the fused silica tube, but pure dry nitrogen was substituted for hydrogen; in order to avoid decarburisation, pure dry nitrogen also being used in the subsequent heat-treatments. The temperature was maintained at 500° C. for thirty minutes, and the bars allowed to cool with the furnace.

7. The temperature of the furnace was maintained from 598° to 600° C. for four hours before allowing to cool.

8. The temperature was maintained at 700° C. for one hour and thirty minutes before cooling.

9. The bars were maintained at a temperature of 798° to 802° C. for one hour and allowed to cool in the furnace.

The results of the various measurements made on the four heat-treated steels are summarised in Tables IV., V., VI., and VII. For ease of comparison, the properties of the four steels in the hardened condition are given in Table VIII. In these tables the ten items given under the first column are as follows:

1. (Hardness.) Brinell number.

2. (Sp. res.) Specific resistance measured at 25° C.

3. (Perm. N.F.) The attractive force of the permanent field of the north pole, measured in dynes at a distance of 1 centimetre.

4. (Demag.) The current in milliamperes required to demagnetise the bar.

5. (Double N.F.) The current in milliamperes required to superpose an induced field equal to that of the permanent north field in (3).

6. (Sum 8 F.) The sum in dynes at 1-centimetre distance of eight magnetic fields induced by applying eight successive magnetising currents in steps of 0·10 ampere each.

7. (F. 5 A.) The magnetic field measured in dynes at a distance of 1 centimetre, due to application of current of 0·50 ampere.

8. (Dy. Bl.) The vertical distance expressed in dynes which the induced field at 0·50 ampere falls below a straight

line connecting the induced fields at 0·10 and 0·80 ampere when the eight induced fields are plotted with the currents as abscissæ. (See Dy. Bl., Fig. 2.)

9. (Dy. Ab.) The vertical distance expressed in dynes which the induced field at 0·50 ampere lies above a straight line connecting the induced fields at 0·10 and 0·80 ampere when the eight induced fields are plotted with the "amperes squared" as abscissæ. (See Dy. Ab., Fig. 2.)

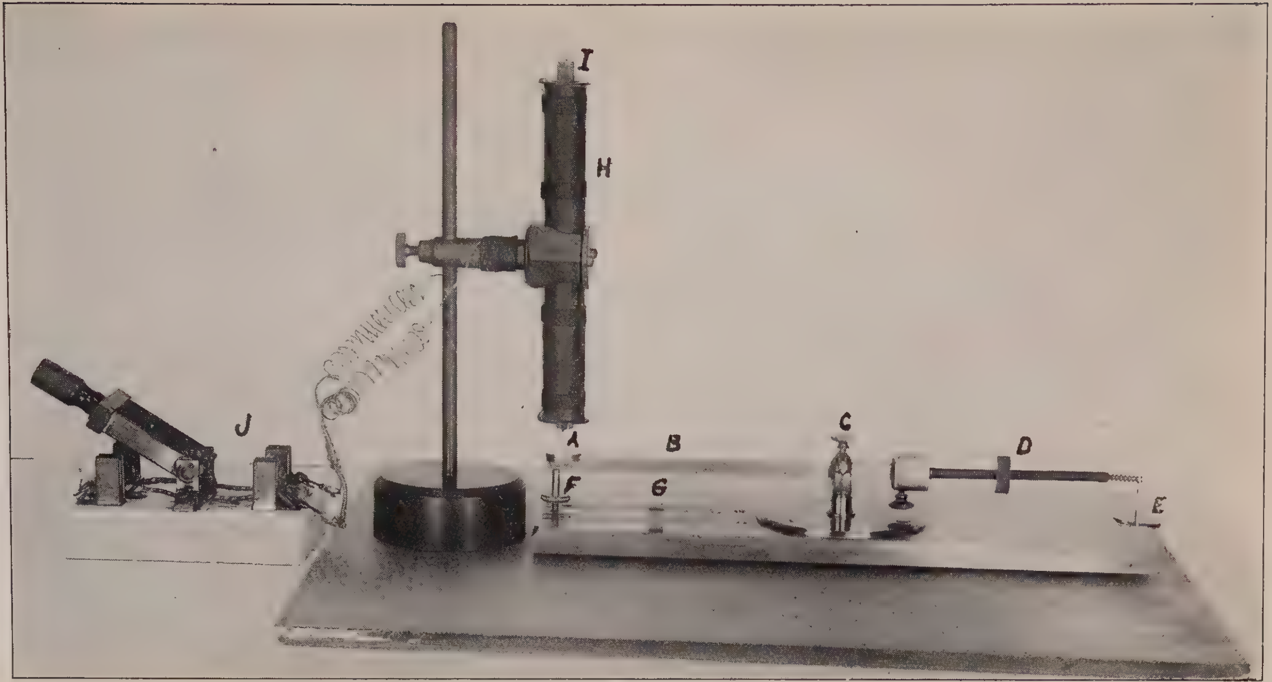
10. (Ratio.) The ratio obtained by dividing the "dynes above" the straight line when values are plotted with "amperes squared" as abscissæ by the "dynes below" when values are plotted with amperes as abscissæ.

In the succeeding nine columns are indicated the temperatures to which the bars were heated subsequent to their hardening, as given in the general description of the heat-treatment.

TABLE IV.—*Influence of Heat-Treatment on the Properties of Steel. No. I.*

Properties.	Tempering and Annealing Temperatures.								
	20° C.	100°.	200°.	300°.	400°.	500°.	600°.	700°.	800°.
1. Hardness .	...	...	...	328	265	228	163	134	101
2. Sp. res. . .	16·85	...	16·04	15·05	14·69	14·59	14·31	14·22	14·39
3. Perm. N.F. .	625	590	480	205	190	200	130	80	15
4. Demag. . .	905	900	750	500	400	400	325	275	150
5. Double N.F. .	425	410	355	210	210	235	130	135	50
6. Sum 8 F. .	6590	6660	6710	6835	6860	6995	7080	7540	8430
7. F. 5 A. . .	805	810	820	850	825	780	845	920	1050
8. Dy. Bl. . .	320	320	320	360	420	420	490	470	445
9. Dy. Ab. . .	50	60	40	25	0	0	−60	−20	35
10. Ratio . .	0·155	0·185	0·125	0·07	0	0	−0·12	−0·04	0·08

In addition to the experiments with heat-treated steels, one with normal "Armco" iron was made to determine the extent to which drastic cold-working would affect the specific resistance and permanent magnetism. One end of a round bar 16 millimetres in diameter was drawn down cold under a hammer until reduced in cross-section to a little more than 6 millimetres square. A piece of the drawn-down portion was then machined to a bar 6 millimetres square by 15 centimetres long. A 6-millimetre


I
H
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A
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E

FIG. 1.—BALANCE AND HOLDER FOR FORCE-FIELD MEASUREMENTS.

[*To face p.* 216.

square bar was machined out of another round bar which had not received any cold-working. The unworked bar had a specific resistance of 10·64 michroms at 25° C., while that of the cold-hammered was 10·86, an increase of but 0·22 microhms.

TABLE V.—*Influence of Heat-Treatment on the Properties of Steel. No. II.*

Properties.	Tempering and Annealing Temperatures.								
	20° C.	100°.	200°.	300°.	400°.	500°.	600°.	700°.	800°.
1. Hardness .	...	...	...	491	407	364	264	202	140
2. Sp. res. . .	30·62	27·12	23·65	19·93	19·15	18·41	17·31	16·78	17·51
3. Perm. N.F. .	1220	1180	1030	460	465	460	390	265	140
4. Demag. . .	1300	1200	1150	650	650	650	500	400	350
5. Double N.F. .	910	825	670	335	350	380	385	322	175
6. Sum 8 F. .	4395	4740	5345	6315	6140	5665	5085	5345	6650
7. F. 5 A . .	605	645	720	810	770	700	590	550	775
8. Dy. Bl. . .	55	50	80	220	260	275	350	520	445
9. Dy. Ab. . .	135	140	160	40	55	25	−60	−185	−60
10. Ratio . .	2·45	2·65	2	0·185	0·212	0·09	−0·17	−0·35	−0·13

TABLE VI.—*Influence of Heat-Treatment on the Properties of Steel. No. III.*

Properties.	Tempering and Annealing Temperatures.								
	20° C.	100°.	200°.	300°.	400°.	500°.	600°.	700°.	800°.
1. Hardness .	...	...	...	488	370	302	231	179	156
2. Sp. res. . .	36·72	30·57	25·38	19·68	18·73	18·40	17·68	17·25	17·52
3. Perm. N.F. .	695	700	775	530	545	675	400	225	115
4. Demag. . .	1325	1275	1175	800	765	825	600	475	400
5. Double N.F. .	805	780	715	387	415	490	350	232	140
6. Sum 8 F. .	2905	3075	3720	5930	5605	5515	5865	6270	7320
7. F. 5 A. . .	390	415	500	785	720	700	705	735	885
8. Dy. Bl. . .	40	30	50	180	200	215	330	335	345
9. Dy. Ab. . .	100	100	120	105	80	70	−10	−60	−15
10. Ratio . .	2·57	3·35	2·4	0·58	0·40	0·32	−0·03	−0·18	−0·04

The permanent north magnetic field of the unworked bar was about 5 dynes, while that of the cold-hammered was 45 dynes, a current of 225 milliamperes being required to demagnetise it. These figures show very clearly that changes in both specific resistance and in permanent magnetism, brought about by drastic cold-working, are relatively very small as compared with those due to changes in concentration or structure of carbides.

TABLE VII.—*Influence of Heat-Treatment on the Properties of Steel. No. IV.*

Properties.	Tempering and Annealing Temperatures.								
	20° C.	100°.	200°.	300°.	400°.	500°.	600°.	700°.	800°.
1. Hardness .	...	...	...	502	387	321	228	207	156
2. Sp. res. . .	43·07	37·45	31·33	23·06	21·79	21·32	20·46	20·04	19·87
3. Perm. N.F. .	490	530	685	685	695	800	405	235	125
4. Demag. . .	1465	1400	1275	900	850	900	650	500	400
5. Double N.F. .	836	835	800	460	462	550	345	230	145
6. Sum 8 F. .	1965	2130	2830	5905	5540	5445	5965	6665	7385
7. F. 5 A. . .	265	295	380	760	710	690	735	795	895
8. Dy. Bl. . .	30	20	40	140	170	175	300	400	335
9. Dy. Ab. . .	60	80	95	120	90	95	10	−35	0
10. Ratio . .	2·05	4·00	2·38	0·83	0·53	0·55	0·03	−0·09	0

TABLE VIII.—*Showing Properties of Steels* 1, 2, 3, 4, *in the Hardened Condition.*

	1.	2.	3.	4.
Sp. res.	16·85	30·62	36·72	43·07
Perm. N.F.	625	1220	695	490
Demag.	905	1300	1325	1465
Double N.F.	425	910	805	836
Sum 8 F.	6590	4395	2905	1965
F. 5 A.	805	605	390	265
Dy. Bl.	320	55	40	30
Dy. Ab.	50	135	100	60
Ratio	0·155	2·45	2·57	2·05

The results obtained with cold-worked "Armco" iron, compared with those from heat-treated steels, as given in Table VIII., indicate that the magneto-motive force, characteristic of permanent magnetism, is primarily due to the force fields of carbides rather than to variformity of structure in the solvent iron.

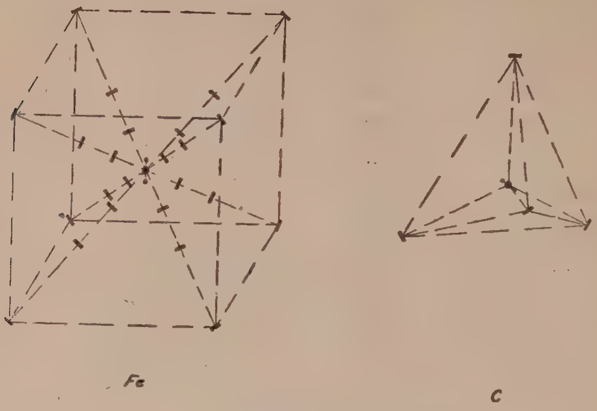
In Table VIII. it will be noted, first, that the specific resistance increases rapidly with the carbide concentration; second, that the permanent north field increases to a maximum with steel number 2 and then falls off decidedly in the case of the two hypereutectoid steels; third, that the current required to demagnetise, which is equivalent to the force necessary to depolarise the carbides, increases continuously with the total carbide concentration, but the increase is relatively small in steels 3 and 4; fourth, that the sum of the eight induced fields, as well as the induced field due to a current of 0·50 ampere, diminishes as the carbide concentration increases, thus indicating apparently that the force fields of carbon ions, resulting from ionic dissociation of dissolved carbides, will produce not only electrical but magnetic resistance as well.

These results may be reasonably explained on the assumption that the carbides have a magneto-motive force which is dependent on the chemical constitution, but is independent of the size of the particles, in a manner similar to the electromotive force of a cell which, as is well known, is wholly dependent upon the chemical composition, but is independent of the size. Since the permanent magnetic field is dependent on both the magneto-motive potential and magnetic resistance, and since the magneto-motive potential increases but slightly above the eutectoid point, while the magnetic resistance increases rapidly, the strongest permanent field can usually be developed by proper heat-treatment of slightly hypoeutectoid steel. Increasing the molecular weight of the carbides by the addition of elements like chromium or tungsten, increases very decidedly the magneto-motive potential without increasing the electrical or magnetic resistance.

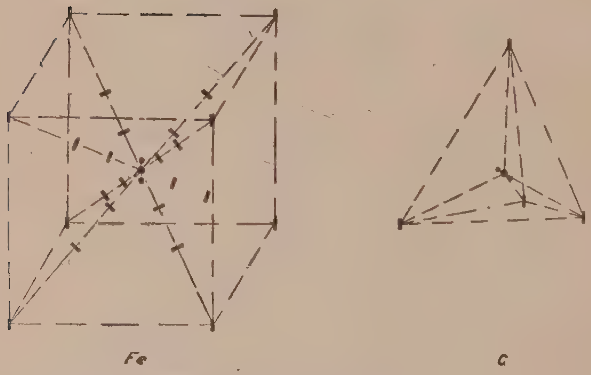
While tempering at relatively low temperatures diminishes the magneto-motive potential of the carbides, the diminution in magnetic resistance, due to decrease in ionic and molecular dissociation, and to transformation of γ to a iron, may frequently more than offset the lowered magneto-motive potential, so that there may be an actual increase in the permanent magnetic field. This is the underlying reason why oil-hardened chrome steel makes a stronger permanent magnet than the same steel quenched in cold water, although the Brinell hardness of the water-hardened steel is the higher of the two.

We would suggest the following hypothesis for the mechanism of permanent magnetism in steel, based on the above experiments, together with the Lewis-Langmuir concept of the iron atom, including the Hull spacing of the electrons and the structure of the carbon atom as shown in Fig. 3.

It is a well-known fact that a continuous ring of pure iron when magnetised will retain a large amount of residual inductance, whereas a straight bar of the same metal will lose practically all of its magnetism as soon as the magnetising field is cut off. In the hypothesis proposed, the planes of rotation of the outer electrons of the iron atoms are oriented into positions at right



NON-MAGNETIZED CONDITION



MAGNETIZED CONDITION

Fig. 3.

angles to the lines of induction in the imposed field, as illustrated in the lower iron atom in Fig. 3. In a continuous ring of pure iron, every iron atom has other iron atoms on both sides, so that when the outer electrons have been all brought into parallel planes of rotation by the imposed field, the planes of rotation of the electrons of a given atom will be maintained by the induction due to the similarly oriented electrons of the neighbouring iron atoms. On the other hand, in the case of a straight bar of pure iron, the outer electrons will, as in the case of a ring, be oriented by the imposed field into parallel planes of rotation, but as soon as the magnetising current is cut off, the outer electrons of the extreme end atoms will be drawn back into their original planes of rotation, at right angles to the cube diagonals by the induction due to the doublets of electrons of the inner shells of the atom, because on one side of the atom there is no magnetic induction to hold them against the induction due to the doublets of the electrons of the inner shells of the atoms. As soon as the outer electrons of the end atom have been drawn back into their normal position, this will remove the induction on one side of the second row of atoms, so that the second row will, like the first, have its outer electrons all drawn back into their original planes of rotation by the induction due to the inner electrons. This process would be repeated throughout the length of the bar, so that in case the bar were free from strain, there would be but little indication of permanent magnetism as soon as the magnetising current is cut off.

An examination of the structure of the carbon atom, as shown in Fig. 3, will suggest the mechanism by means of which the outer electrons of the iron atoms are held in the planes of rotation, to which they have been brought by the imposed field. In the carbon atom there are no doublets of inner electrons, so that, although a much stronger force is required to orient the planes of rotation of the four outer electrons into positions parallel to those of the outer electrons of surrounding iron atoms, when this orientation is once effected, the electrons of the carbon atoms will, on the principle of a gyroscope, retain the plane of rotation into which they have been brought by the imposed field, and the induction due to the electrons of the carbon atoms will be sufficient to hold the outer electrons of immediately adjacent iron atoms against the induction due to the doublets of the inner electrons of the latter. When there are two or more carbon atoms in the same molecule, it would be natural to expect that the induction, due to the greater number of electrons, would be increased, hence that the magneto-motive potential of the carbides would be a function of the molecular weight. Bringing the planes of rotation of the electrons of the carbon atoms of the carbides into parallel position would result in an alignment of the force fields of the latter. By a serial alignment of the poles of the force fields of the carbides, there will result a cumulative effect of the magneto-motive forces of the carbides in a manner similar to the cumulative electromotive force resulting from the serial connection of cells. The energy represented in the pole fields of the permanent magnet would thus seem to be derived more from the internal energy of the carbides than from the internal energy of the atoms of the solvent iron, this latter serving principally as a conductor of the lines of force due to the carbides.

Since the magneto-motive potential of carbides is dependent on the molecular constitution and not on size of the particles, the maximum magneto-motive potential would naturally be found when the carbides are in solution.

INFLUENCE OF DISSOLVED OXIDES ON THE CARBURISING AND HARDENING QUALITIES OF STEEL.

By E. W. EHN (Canton, Ohio, U.S.A.).

Author's Reply to Correspondence.[1]

Mr. Ehn, in reply to the discussion on his paper, wrote that he was aware that the proof for his theories was largely circumstantial, and that the different points in favour of his contention that dissolved oxides were the cause of the variations in carburising properties, taken one by one, might not be entirely convincing, although they combined to form conclusive proof for the soundness of those theories, and were fundamentally correct even if later experiences might necessitate modifications as to minor details. In view of the rather severe criticism in part of the discussion it was very gratifying that such an eminent and recognised authority on the subject as Professor Portevin stated that his experiments entirely confirmed the theories. There was also one point that should be borne in mind, and that was that those theories actually worked out in practice, and that tests of that kind on steel had been used with great success at several plants.

In answer to Mr. Saniter he pointed out that the experiences recorded in the paper showed that, after carburising a normal steel burnt in a forge fire, strongly segregated cementite was found (Fig. 23), and that that change in the carburising qualities of the steel could be gradually followed to the parts of the bar not subjected to the high temperature. That experiment seemed to afford at least one instance where there could not be the slightest doubt as to the reason for the segregated structure.

Colonel Belaiew's objection that the difference in grain size between normal and abnormal steel could be properly explained only by conditions during the solidification of the steel in the ingot, were anticipated in the paper, and the opinion of Dr. Giollitti, who on that subject had undisputed authority, was given (p. 186). On p. 187 of the paper was also given an explanation based on the influence of impurities during the secondary crystallisation when the steel passed through its critical points, and it could be pointed out that that explanation was in very close accord with the theories of crystallisation that had lately been published by Messrs. Jeffries and Archer.[1] In experimenting with additions of thoria to tungsten they found that, under certain conditions, the additions of a small amount of thoria refined the grain, but that more thoria caused germination, with the production of a large grain size. He (Mr. Ehn) had several reasons to believe that exact correspondence with those phenomena was obtained with iron and steel, and that the obstructing material that largely regulated the grain size consisted of oxides (see Figs. 25 to 28 and 29 and 30). In Fig. 25 the amount of impurities was very large, causing divorce of pearlite and large grain size. With diminishing amount of impurities smaller grain size was obtained (Figs. 26 and 27), and with the thoroughly deoxidised steel the structure showed large grain size without divorce of pearlite.

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[1] Owing to Mr. Ehn's reply not having been received in time to be published in the volume in which his paper and the correspondence thereon appeared (see *Journal*, 1922, No. I. pp. 157–197), it has been necessary to include it in the present volume. [Editor.]

The way the grain size was controlled was presumably that when a steel, whether normal or abnormal, passed the critical points, a recrystallisation took place. In the case of a normal steel the grain size would grow if the steel were held at a high enough temperature, as, for instance, in a carburising operation, but in an abnormal steel the impurities, when present in proper concentration, prevented the grain growth. That was also an exact parallel to the phenomenon that pure brass when annealed would grow in grain size, but if contaminated by iron the grain size would remain small. He was at present trying to determine more accurately the factors that governed the grain size in steel in carburising, and it was hoped that those experiments could be broadened later on so as to comprise the general question of grain size in steel round and below the Ac3 point.

Dr. Rosenhain's suggestion of using cupric etching reagents as a detector of non-metallic impurities could not be adopted for uniformly abnormal steel, as those reagents would show, not the presence of evenly distributed impurities in the steel, but only the variation in the amount of impurities present in various parts of the sections. Cupric reagents were actually tried on an early stage of those investigations and good results were obtained where mixed portions of normal and abnormal steel were present in the same section, for instance, in steel containing ghost lines, and the results clearly indicated impurities in the abnormal parts of the section. The steel used in the investigation, however, generally showed a uniformly distributed pearlite with little or no tendency to band, and it was found that with such steel the cupric reagent was not sensitive enough to detect noticeable differences in abnormal and normal steel.

Dr. Hatfield's remarks plainly indicated that he had restricted his reading of the paper to the summary, and that even that reading had been perfunctory. He (Mr. Ehn) did not claim, as Dr. Hatfield's discussion indicated, that soft spots were always due to oxides dissolved in the steel, but that that often was the case. He was thoroughly aware of the importance of a proper hardening, and if Dr. Hatfield had read the paper he would have noticed that a very liberal portion was devoted to cover exactly that point. The plant with which the author was connected had one of the largest carburising and hardening departments in the United States, equipped with special automatically controlled furnaces and hardening machines with a minimum possibility for variation in their hardening practice.

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[1] "Grain Growth and Recrystallisation in Metals," *Chemical and Metallurgical Engineering*, February 22, March 1, and March 9, 1922.

Professor Portevin's contribution to the discussion, with its confirmation of the author's conclusions, was very welcome, especially on account of Professor Portevin's recognised authority on the subject. In regard to the statement that he (Mr. Ehn), in the course of an electric furnace heat, had not noticed any material variation in carburising qualities of the steel, attention might be called to the fact already mentioned in the paper that several electric heats tested in the way showed perfectly normal carburising qualities all through the heat. That experience was thus not necessarily contradictory to that of Professor Portevin. Professor Portevin mentioned that his experiments were mainly started in order to obtain a method for qualitative determination of the degree of deoxidation of steel, and he (Mr. Ehn) believed that was perfectly feasible. It was indeed possible to obtain a complete series of structures that gradually with small changes covered the entire field between normal and abnormal structure, and the experience had been that with that change in structure there was simultaneously a change in the way the steel responded to the hardening operation. That change in structure was presumably due to the degree of deoxidation of the steel and the presence therein of non-metallic impurities. Just what the nature of those impurities were was very difficult to ascertain, but they were presumably oxides of complex composition. Aluminium would, for instance, invariably, when added to a molten steel, rich in gases, produce, after carburising, a structure, such as shown in Fig. 30, and it was reasonable to assume that other types not shown in the paper were connected with varying compositions and concentration of the impurities. That would afford a method for checking the way the steel had been made and deoxidised, and a systematic study of carburised structures was therefore likely to yield important results.

VISITS AND EXCURSIONS AT THE AUTUMN MEETING AT YORK.

The decision to hold the Autumn Meeting at York instead of London, as had originally been intended, was due to a number of circumstances, amongst which, however, the controlling factor was the hospitable invitation extended to the members by Mr. Charles Markham to visit the works of the Staveley and of the Park Gate Companies. Both Sheffield and Leeds had been, in comparatively recent years, the hosts of the Institute under more auspicious trade conditions than those which prevailed at the time, while precedent for choosing a centre not connected with the iron and steel industries existed in the selection, in 1910, of Buxton as the place of meeting. These considerations influenced the Council, therefore, in their choice of York, which it was felt would, by its historical, antiquarian, and architectural interest, afford a welcome change from a big industrial city, and at the same time be within easy reach of a large proportion of the membership, and a convenient starting point for the visits to Staveley and Park Gate.

In the result the expectations entertained were more than realised, for by the courtesy of the Yorkshire Philosophical Society the business sessions were held in the Tempest Anderson Hall of the Museum, of which the Society is the custodian, and the Museum and the beautiful grounds surrounding it being placed fully at the disposal of the visitors, the meetings were held amongst charming surroundings, which did much to justify the choice of the locality. Although the attendance was smaller than that usually recorded at an Autumn Meeting, owing doubtless to the unsettled state of trade, some 250 members and ladies registered their names at the Secretary's office, and the Council are gratified to feel that those who attended unanimously expressed the view that the selection of York had been a happy one, and that, in its amenities, no less than in its more practical aspects, the meeting had been both a successful and a pleasant occasion. In this connection the Council desire to place on record their obligations to the President and Council of the Yorkshire Philosophical Society for the hospitality extended, and to Dr. Walter E. Collinge, the Keeper of the Museum, who did all he could for the comfort and enjoyment of the members, and to whom they gladly recognise their indebtedness. They also wish to express their warm thanks to the Board of the North Eastern Railway, and to the general manager, Mr. R. C. Wedgwood, C.B., C.M.G., for their generous treatment of the members in connection with the special trains from York to Staveley and to Park Gate. Notwithstanding that the members participating in the arrangements made were smaller than on previous but similar occasions, owing to the fact that many of the members who visited the works in question travelled independently, the arrangements made by the North Eastern Company were on a most generous scale, and both Mr. Kerr, the chief passenger manager, and Mr. Rowland deserve the best thanks of the Institute for the trouble they took to ensure the comfort and convenience of the visitors.

At the General Meeting held on the morning of Tuesday, September 5, under the chairmanship of the President, Mr. Francis Samuelson, the Deputy Lord Mayor of York, Mr. Alderman E. Walker (in the unavoidable absence of the Lord Mayor), attended by the Town Clerk and the Sword and Mace Bearers of the city of York, welcomed the Institute to York, and expressed his gratification at the selection of that city as the place of meeting, and Mr. Wedgwood welcomed the members on behalf of the chairman and directors of the North Eastern Railway. The usual business session followed, and after luncheon a further session was held until 4.30 P.M., when it was adjourned to the following morning, and the members and ladies attending proceeded to the Festival Concert Rooms, where an exceedingly interesting film demonstration was given by Mr. William McConway of Pittsburgh, U.S.A., descriptive of his new process for the production of steel discs by centrifugal-hydraulic casting direct from molten steel. Tea and light refreshments were served, and at the conclusion of the demonstration the President proposed a hearty vote of thanks to Mr. McConway for his highly interesting demonstration. A fuller account of the process will be found on p. 249.

In the afternoon of Wednesday, September 6, a garden party was held in the grounds of the Yorkshire Philosophical Society, and was well attended. The weather, though somewhat overcast, remained fine, and members were thus enabled to visit in comfort the interesting ruins of St. Mary's Abbey and St. Leonard's Hospital, as well as the other remains of historic buildings within the grounds. Parties were conducted by Dr. Collinge, the Keeper of the Museum, and by Mr. Elmhirst, the Honorary Secretary of the Society. Tea and light refreshments were served in a large marquee in the middle of the lawns, and a programme of music was performed on the terrace in front of the Museum by Mr. Albert Bartley's Orchestra.

An invitation having been received from Messrs. T. Cooke & Sons, engineers, opticians, and scientific instrument makers, to visit their works, a number of members availed themselves of the opportunity so kindly provided, and spent some time in viewing the workshops of the company at the Buckingham Works in the centre of York. A description of the works will be found on p. 236.

In the evening a conversazione and dance were held in the Corporation Art Gallery, kindly lent for this occasion by the city authorities. The President, Mr. Francis Samuelson, with Miss Samuelson and other members of his family, received the members in the main hall, while dancing took place in the long gallery on the first floor of the building. A buffet supper was served in the main hall by Messrs. Terry of York, to whom had been entrusted the arrangements for the garden party earlier in the day, and who likewise provided the dinner and wines on the following evening at the Assembly Rooms, while Mr. Bartley's band again supplied the music. The thanks of the Council are tendered to the curator, Mr. Kirby, O.B.E., and to his staff, for the excellent way in which the arrangements were carried out.

Thursday, September 7, was devoted to visiting the Devonshire Works of the Staveley Coal & Iron Company, on the kind invitation of Mr. Charles Markham and his co-directors. A special train left York at 9.50 A.M., arriving at Staveley (Midland station) at 11.16. Here the members, whose numbers were considerably increased by those who had travelled to Staveley independently, were met by Mr. Markham, chairman of the company, supported by Mr. A. Westlake, managing director, and by Mr. R. Whitehead and Mr. Blayden. After visiting the blast-furnace and coking plant the visitors were entertained at luncheon, Mr. Markham presiding, and the repast being served in the new sulphate house, which had been specially decorated for the occasion. Mr. Markham made a felicitous speech, welcoming his guests, and giving a brief account of the history and development of the works, after which the President, Mr. Francis Samuelson, proposed a hearty vote of thanks to Mr. Markham and his co-directors, and the visits of inspection were resumed. A special train, leaving Staveley at 4.55 P.M., brought the main party back to York on the conclusion of a most enjoyable day. A description of the works will be found on p. 237. Alternatively a party of fifty members and ladies spent the afternoon of this day in a motor charabanc excursion to Rievaulx Abbey. Special conveyances started at 1.15 P.M. from the North Eastern Station hotel, and reached Rievaulx soon after 3 P.M. Tea was served by permission of His Majesty's Board of Works and of Colonel Duncombe and the Duncombe Park Trustees, on the terrace overlooking the Abbey, which is situated in a sheltered and well-wooded valley. As the time was limited only a few of the bolder spirits ventured to visit the Abbey ruins themselves, the steepness of the approaches debarring the majority from risking the enterprise.

Rievaulx Abbey is situated about three miles from Helmsley, a small country town of considerable antiquarian interest. It was the first Cistercian Monastery in Yorkshire, and the parent Abbey of the order throughout the country, having been founded in 1311 by Walter de l'Espec. After Edward the Second had unsuccessfully attempted to invade Scotland he took refuge for a time at Rievaulx. One of the features of the Abbey was the magnificent Norman lancet windows of the transept. At one time the Abbey formed part of the Buckingham Estates.

The celebrated Terrace which is close to the Abbey was built by Thomas Duncombe in 1750, and took eight years to build. It is half a mile in length, and has a temple at each end, the Terrace itself commanding splendid views of the Abbey and of the valley in which it stands. The north temple, which was thrown open for the inspection of the members, has a fresco ceiling painted by Burnice. The property belongs to Lord Feversham, and there is a handsome monument to the memory of the Second Baron Feversham in Helmsley. Duncombe Park and Mansion have for many generations been the residence of the Duncombes, having been purchased from the executors of the Duke of Buckingham in 1700. The Mansion was partially destroyed by fire in 1879. The Abbey itself and the Terrace are now National Monuments, and their care devolves on His Majesty's Commissioner for Works and Public Buildings.

In the evening the members assembled at an informal dinner held in the Assembly Rooms, Blake Street. At the conclusion of the repast the Deputy Lord Mayor of York, Mr. Alderman Walker, made what he described as his 2000th speech, and again welcomed the members to that city, of the archæological and historical interest of which he gave a brief account. He then proposed the toast of the Iron and Steel Institute, and of its President, which was duly honoured. Mr. Samuelson replied, and in a humorous speech, which was all too short for his hearers, reviewed the circumstances under which the Council came to select York as the place of meeting. Speeches were also made by Mr. F. W. Harbord, C.B.E., Member of Council, by Lady Fisher-Smith, by Dr. Walter E. Collinge, and by Mr. G. C. Lloyd, Secretary.

The concluding event of the meeting was the visit paid on Friday, September 8, to the works of the Park Gate Iron and Steel Company, Rotherham, on the kind invitation of its chairman, Mr. Charles Markham, and the directors of the company. The departure from York, as on the day before, was timed for 9.50 A.M., and the special train reached the Rawmarsh station of the Midland Railway at 10.44 A.M. Here the York contingent was again heavily reinforced by members from Sheffield, Leeds, and adjacent districts, who had travelled to their destination by other routes. The visitors on arrival were greeted by Mr. Charles Markham, chairman of the Park Gate Company, with whom were Mr. P. W. Fawcett and Mr. F. Phillips, joint managing directors, Mr. Fred Clements, and Mr. H. Royston, general manager. After visiting the blast-furnaces and the steelworks, the visitors were entertained at luncheon in a large hall adjacent to the works offices.

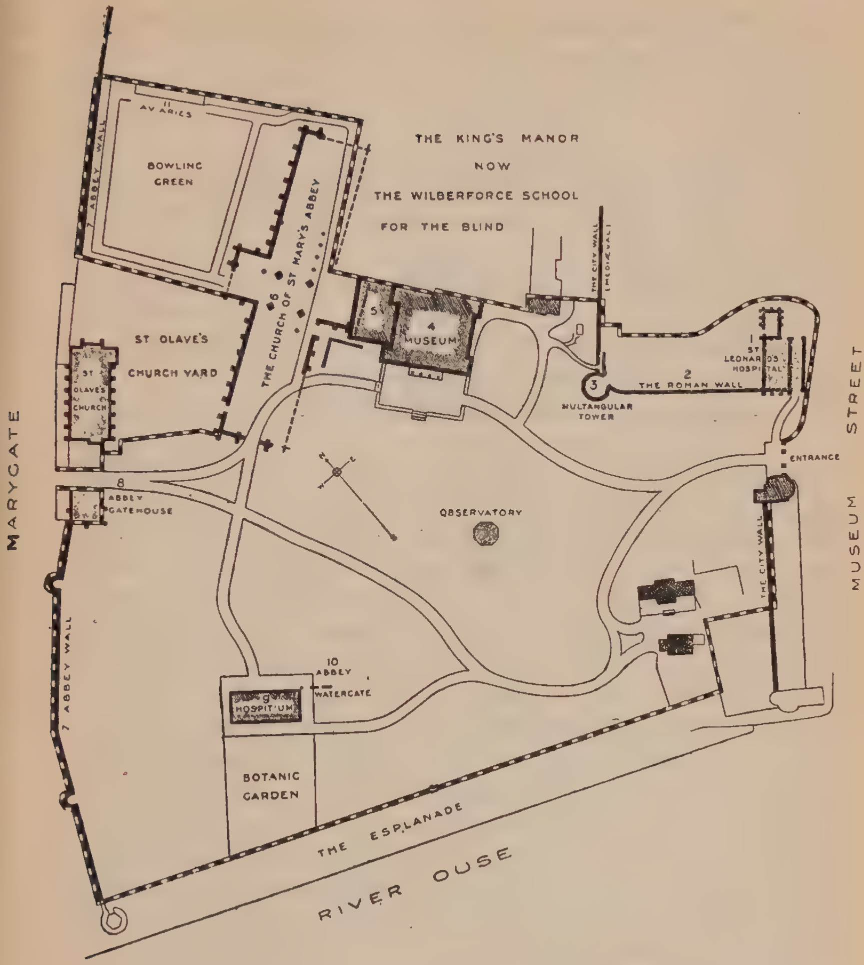
Mr. Charles Markham again presided. At the conclusion of the luncheon Mr. Francis Samuelson, President of the Iron and Steel Institute, proposed the health of the chairman and of the company, and the toast having been duly honoured by acclamation, Mr. Markham responded in a speech of no little humour, which was received with much applause. The visits were then resumed, the rolling-mill plant being inspected, and at the close of the proceedings the members departed with a sense of having been received and entertained, both at Staveley and at Park Gate, with a warmth and hospitality which have not been exceeded at any previous visit paid to works on the occasion of an Autumn Meeting, and with the recollection of a most interesting occasion rendered doubly so by the pains taken by their hosts for their convenience and enjoyment. An account of the works will be found on p. 241.

NOTES ON PLACES AND WORKS VISITED.

The Yorkshire Philosophical Society, York, was founded in 1822, and in 1829 acquired about four acres of the present site, formerly known as the Manor Shore, which consisted of pasture land, and on which stood farm buildings. The building of a Museum was at once begun, and excavations were undertaken to ascertain the extent and nature of the buildings which formed the Benedictine Abbey of St. Mary. The grounds belonging to the Abbey covered about fifteen acres, and of this the Manor Shore formed a part. Extensions have been made at various times to the Society's grounds, which now cover more than ten acres. The accompanying map shows a plan of the grounds, indicating the position of the Roman, Mediæval, and Modern Buildings.

The Abbey Gatehouse is now a private dwelling and is not shown to visitors.

Their Majesties the King and Queen and Queen Alexandra are patrons of the Society, the President of which is Dr. William Herbert St. Quentin. The Honorary Treasurer is Mr. Edward Gray, and the Honorary Secretary, Mr. Charles E. Elmhirst. Dr. Walter E. Collinge is the Keeper of the Museum.


11 AVIARIES
BOWLING GREEN
7 ABBEY WALL
THE KING'S MANOR NOW THE WILBERFORCE SCHOOL FOR THE BLIND
THE CHURCH OF ST MARY'S ABBEY
6
5
4 MUSEUM
THE CITY WALL (MEDIÆVAL)
1 ST LEONARD'S HOSPITAL
2 THE ROMAN WALL
3 MULTANGULAR TOWER
ST OLAVE'S CHURCH YARD
ST OLAVE'S CHURCH
MARYGATE
8 ABBEY GATEHOUSE
OBSERVATORY
ENTRANCE
MUSEUM STREET
THE CITY WALL
7 ABBEY WALL
10 ABBEY WATERGATE
9 HOSPITIUM
BOTANIC GARDEN
THE ESPLANADE
RIVER OUSE

Plan of the Society's Grounds, showing the position of the Roman, Mediæval, and Modern Buildings.

REFERENCES.

1.—Hospital of St. Leonard, founded 937 and rebuilt 1108–1114.

2.—Part of the Roman Wall of Eboracum (*i.e.*, York).

3.—The Roman Multangular Tower. The upper portion is Mediæval.

4.—The Yorkshire Museum, containing Natural History and Antiquarian collections.

5.—The "Tempest Anderson" Lecture Hall, below which is the Vestibule of the Chapter House, now a Mediæval Architectural Museum.

6.—The Ruins of the Church of St. Mary's Abbey.

7.—Part of the Wall built in 1265, which formerly surrounded the Abbey precincts.

8.—The Gatehouse of St. Mary's Abbey (now a private residence).

9.—The "Hospitium" of St. Mary's Abbey (now a Museum of Roman Antiquities and Mediæval Pottery).

10.—The Watergate of St. Mary's Abbey.

1. *St. Leonard's Hospital.*—An earlier Hospital dedicated to St. Peter, on a neighbouring site, was built by King Athelstan in the year 937 to commemorate his victory over the Scots. It was rebuilt by Archbishop Thomas (1108–1114), who enlarged the site and rededicated it to St. Leonard. It was suppressed by King Henry VIII. in 1539. The portions that remain are the Ambulatory with a vaulted roof, above which are the ruins of the Dormitory and Chapel.

2. *The Roman Wall.*—Eboracum (now York) was rectangular in shape and measured 540 yards by 480 yards. It was surrounded by a stone wall built during the reign of the Emperor Trajan (98–117).

3. *The Multangular Tower.*—This Tower and the adjoining portions of the Roman Wall formed the south-western corner of Eboracum. The upper part is Mediæval and dates from about the reign of Edward III. .

4. *The Yorkshire Museum.*—Built in 1829. It contains Natural History and other collections.

In one of the rooms will be found the fossil remains of the Ichthyosaurus and other Saurians, also the fossil remains of the Cave Lion, Hippopotamus, Mammoth, and other extinct animals from the Kirkdale Cave. Among other interesting objects are the Bell-Metal Mortar of the Infirmary of St. Mary's Abbey, a Meteorite which fell near Middlesbrough in 1881, and, in the Central Hall, a glass case containing the fetters and chains worn by Dick Turpin while imprisoned in York Castle in 1739. The Ethnological Collection is reached by ascending the staircase immediately through the door on the left-hand side of the Entrance Hall. It contains a number of prehistoric remains from the "Barrows" of Arras, an ancient British canoe, ancient arrow-heads, axes and other implements of the Stone and Bronze Ages. Another staircase just beyond the one already mentioned leads down to the Vestibule of the Chapter House of St. Mary's Abbey.

5. *Vestibule of the Chapter House of St. Mary's Abbey.*—All the pillars of this once beautiful building are still *in situ*. It now serves as a mediæval architectural Museum and contains stone fragments found at various times during excavations in the Abbey precincts and elsewhere in York. Among the most interesting are those of the demolished shrine of St. William (Archbishop of York, 1154) which formerly stood behind the high Altar in the Minster, also a portion of the great Reredos of the high Altar itself, a fine series of statues found in 1828 under the pavement of the south aisle of the Nave of St. Mary's Abbey Church, and a number of fine vaulting Bosses from the Choir. Above the Vestibule is the "Tempest Anderson" Lecture Hall, built in 1912. A doorway at the foot of the staircase leads to the ancient fireplace of the Refectory.

6. *Church of St. Mary's Abbey.*—Until the year 1900 the greater part of the foundations of the Choir remained hidden below the surface of the ground. Excavations in 1912 have uncovered the foundations of four out of the seven apses of the eastern termination of the Norman Abbey Church as well as the platform wall of the South Arcade of the Choir. The Church, the foundation-stone of which was laid by William Rufus, was destroyed by fire in 1137. The ruins now seen are those of the Church, the building of which was begun in 1271 by Simon de Warwick, Abbot, from 1259 to 1299. Through the north door of the Nave may be seen the tomb of William Etty, R.A., born in York, 1787, who died 1849. The small indentations in the wall of the adjoining bay were caused by musket-balls, the open space in front having been used as a musketry ground during the early part of the nineteenth century, when Napoleon Bonaparte was preparing to invade England.

7. *Portions of the Wall.*—Portions of the Wall which the

Abbot, Simon de Warwick, built in 1265 to protect the Abbey and its precincts from external attacks.

8. *Gatehouse of St. Mary's Abbey.*—The upper part was probably where the Abbot held his Courts, and the lower part was the prison of the Abbey. Formerly the Gateway had a groined roof, and the Gatehouse extended over it.

9. *The Hospitium.*—Believed to have been the "Guest House" of the Abbey, but the building has undergone many alterations in the course of time.

It contains one of the finest collections in the kingdom of local Roman pottery and glass, and of Mediæval pottery, also the hair of a Roman lady dating from about the third century. The coffin in which the body bearing this hair was found, is to be distinguished from the other Roman coffins by its inner lining of lead.

The Hospitium also contains Roman pavements, sculptures, coffins, and a few Saxon and Norman sculptures.

10. *The Watergate.*—The Watergate which gave access to the staith or landing belonging to the Abbey.

MESSRS. T. COOKE & SONS, LIMITED, BUCKINGHAM WORKS, YORK.

The firm of Messrs. T. Cooke & Sons, Limited, was founded 80 years ago, and specialises in the manufacture of large astronomical telescopes and surveying instruments, the theodolites used by Captain Scott on his Antarctic Expedition having been supplied by the firm. During the war they were largely employed in making range-finders, gun-sights, periscopes, and signalling appliances. For many years past the firm has held the distinction of having been appointed by the British Engineering Standard Committee sole makers of standard and commercial templates for British Standard Section tramway and railway rails. Another speciality of the firm is apparatus for the pneumatic dispatch of papers, letters, &c., both for the post office and telegraph services and for banks, railway offices, and commercial firms. Amongst the optical instruments manufactured by Messrs. T. Cooke & Sons may be mentioned the well-known "Cooke Photographic Lens." The works are very extensive and thoroughly equipped with the most modern plant and machinery, the number of skilled craftsmen employed being no less than 450.

THE DEVONSHIRE IRON WORKS.[1]

The Devonshire Works of the Staveley Coal and Iron Company, Limited, consist in the main of a thoroughly modern and up-to-date blast-furnace plant, one of the largest coke-oven plants in the kingdom, and extensive pipe foundries for the manufacture of the cast iron pipes for which the company is so widely and favourably known. The works likewise comprise a large by-product recovery plant, and chemical plant for the manufacture of sulphuric and nitric acids, and other chemicals.

Although the company's works at Staveley are amongst the oldest in the country, having records dating back to 1702, the Devonshire Works are comparatively new. The existing blast-furnaces are all of the most modern type, three of them having been built in 1906, while the fourth was built some years later. Of the three earlier furnaces, No. 3 has quite recently been entirely remodelled, and is now the largest blast-furnace in the Midlands.

In laying down the blast-furnace plant the company was in the favoured position of having ample room for developments, and was therefore able to make the plant spacious and convenient. The four furnaces have been arranged in symmetrical pairs, the distance between centres being no less than 125 feet. Each of the furnaces has its own battery of three Cowper stoves with extra high tops (75 feet) and an equaliser, while the connections are such that any stove or equaliser can be used at need for any furnace, and either hot or cold blast employed as required. The elasticity of the plant is such that a very wide temperature range, varying from that of the surrounding atmosphere up to 1500° F., with, on the other hand, a minimum variation when equalisers are in use, is available, and the temperature conditions are therefore completely under control. The dimensions of No. 3 furnace are as follows: Height, 71 feet; diameter of hearth, 14 feet 9 inches; diameter of bosh, 19 feet 6 inches; height of bosh,

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[1] For this description the Council are indebted to *The Engineer* (September 8, 1922).

(from tuyeres), 11 feet 6 inches; diameter of bell, 11 feet; diameter at stockline, 16 feet.

The rated output is 1200 tons per week, but this has been exceeded. The burthen is a mixture of Lincolnshire, Northamptonshire, and Leicestershire ores containing on an average 32 per cent. of iron, and usually heavily charged with moisture. The coke consumption averages something under 28 cwt. per ton of pig iron produced, the carbon equivalent being about 23 tons.

As the coke is somewhat friable by nature, and as the ore (which is charged raw) varies considerably in mechanical condition and size, the preparation and distribution of the charge is the subject of special care and consideration. Large lumps are crushed between rollers and revolving tables employed for picking and sizing, while the charging arrangements and the furnace-top construction are similar to those adopted at Park Gate. Charging is effected in skips raised by two steam-driven Otis type hoisting engines supplied with cut-out gear to prevent overwinding, and controlled from a cabin in which, as at Park Gate, the mechanic has before him a model of the furnace top, and can superintend every phase of the charging. The furnace top is of the double bell and revolving hopper type.

Blast is supplied by five Galloway vertical blowing-engines with 90-inch blowing cylinders, each capable of delivering from 20,000 to 22,000 cubic feet of air per minute. The blast pressure varies from 8 lbs. to 9 lbs. per square inch. The quantity of air required by No. 3 furnace amounts to 25,000 cubic feet per minute, and to heat this amount four stoves are at present being employed.

The Sahlin water-cooled boshes formerly fitted to this and to the other furnaces have recently been superseded by "Spray" boshes. The pig iron, which is a high-grade and remarkably even-grained and homogeneous foundry iron, is open cast in sand-beds and lifted by two overhead conveyors by which it is taken to Lowca pig-breaking machines, of which two have been installed.

The boiler equipment consists of eight two-drum gas-fired Babcock and Wilcox boilers evaporating 18,000 lbs. of water per hour and raising steam at 160 lbs. to 200 lbs. pressure. Superheat up to 200° F. is employed. A new plant of four three-drum boilers has been installed capable of using coke-oven gases, for which they are primarily designed, or for auxiliary oil firing.

The blast-furnace gases are passed into Dick patent dust catchers, each 21 feet 6 inches in diameter and 51 feet in height, lined with 4½ inches of fire-brick. As at Park Gate, the dust impinges on a cone, and about 90 per cent. is thus eliminated.

The coke-ovens at Staveley represent the very latest by-product coking practice. They consist of an older battery of 100 Simplex horizontal-flue coke-ovens, and a battery of 50 Huessener ovens, besides a new plant of 100 Simplex vertical-flue coke-ovens disposed in three batteries, making in all 250 ovens capable of coking 12,000 tons of coal per week. The coal used is wet slack containing on an average 12 per cent. of moisture. The plant is equipped with all the necessary auxiliaries, such as coal-handling machinery, storage bunkers, mechanical chargers, coal-crushing plant, and electrically driven coal stamping, charging, and discharging machinery, together with a very complete and extensive by-product recovery plant for treating the gases and tar.

The whole installation is one of great interest, particularly in view of the engineering difficulties which had to be surmounted during its construction. The area upon which it is built was in close proximity with seams of workable coal, up to 20 inches in thickness, which actually underlay, at no great depth, portions of the site. The ovens were therefore carried on a solid brickwork platform, supported by arches, and an elaborate system of subterranean ventilators had to be adopted to keep the foundations as cool as possible.

It has been said of the modern blast-furnace that its most valuable function is that of a gas-producer, with a merchantable by-product—the pig iron. The Devonshire works of the Staveley Coal and Iron Company, in its coke-oven and by-product recovery plant, exemplifies the modern tendency for a coking plant to be a chemical works first, and a coke-producer only perhaps in a secondary degree. The whole of the coke-oven gases are passed to the recovery plants, of which the sections dealing with benzol alone have an output capacity of 40,000 gallons per week. As the product is treated in its final stages by the Staveley patent desulphurising process, the "sulphur-free" Staveley benzol has established its reputation for well-refined and high-grade qualities.

Sulphate of ammonia is recovered by sulphatation with acid, made by the company in an adjoining sulphuric acid plant, while oleum, a term which has replaced the name Nordhausen acid, for the concentrated fuming sulphuric acid required in nitrating processes, and nitric acid are also manufactured. A new plant has just been installed to increase the output of sulphuric acid for the manufacture of caustic soda by the electrolytic process. Other products made in the chemical plant are bleaching powder, salt cake, and muriatic acid; iron oxide for pigment and other purposes (recovered from the spent pyrites used in making sulphuric acid), muriatic (hydrochloric) acid, and various proprietary chemicals, such as Wormite (a fumigant for the soil), and Staveho, a waterproofing cement.

In the by-products recovery plant proper, and in addition to benzol, sulphate of ammonia, and tar—the "stock" products of every by-product plant—plant and machinery have been installed for the manufacture of ammonium chloride (sal ammoniac), aniline, and aniline salt; solvent and heavy naphtha; naphthalene, in its immediate commercial forms (crude, pressed, flaked, powdered, and in balls and tablets), anthracene, pyridine, carbolic acid and powder, cresylic acid, green oil, tar, pitch, and black varnish.

Staveley cast iron pipes have achieved a world-wide reputation for soundness and stanchness. They are made from cupola metal in the adjoining foundries in the older plant of the works, and cast vertically in capacious beds. The water required for the various operations about the works, including the cooling of the blast-furnace tuyeres, quenching coke, &c., is obtained from the river Rother and from a canal which traverses the works. The pumping plant comprises one 26-inch by 30-inch hydraulic pumping engine serving the cranes, &c., at the foundries, and several batteries of Sulzer centrifugal pumps, the aggregate capacity of the plant being 13 million gallons of water per day. The generating plant consists of a 3000-kilowatt and a 5000-kilowatt turbo-generator made by the British Westinghouse Company, and driven by exhaust steam from the blast-furnace blowing-engines, and a 1000-kilowatt turbo-generator housed in the blowing-engine house. Current is generated at 6600 volts for transmission to the collieries and to various parts of the plant. In addition to the foregoing two Browett Lindley steam-engines and generators (1000 kilowatts and 500 kilowatts) have been installed generating 220–240 direct current for various works' services.

THE PARK GATE WORKS.[1]

The Park Gate Works were founded in 1823, and became the property of the Park Gate Company in 1864. At that time they consisted of a blast-furnace, puddling furnaces and rolling mills, and the output consisted chiefly of iron rails. The puddling furnaces were dismantled in 1908. It is interesting to note that the plates for the *Great Eastern* were rolled at the works, and also that the plate mill was the first reversing rolling mill to be installed in the country. At one period, likewise, the company was the only one engaged in the manufacture of armour plate, while it was at Park Gate that the first Bessemer ingots, made in Sheffield, were rolled.

Blast-Furnace Plant.

The blast-furnace plant at Park Gate consists of three furnaces —No. 1, rated at 900 tons per week and equipped with three Cowper stoves and an equaliser ; No. 2, rated at 900 tons per week and similarly equipped ; and No. 3, rated at 1000 tons per week, but more often averaging 1100 tons and having to date a record output of 1148 tons, the equipment of which comprises a battery of four Cowper stoves, 75 ft. high and 21 ft. in diameter. Furnaces Nos. 1 and 2 were built sixteen years ago, and have been in continuous operation ever since, with only one relining. No. 3 is a new furnace, built during the war and blown in during July 1918. For the full dimensions and for details and drawings of the furnace top, reference may be made to the schedules published in the paper on "Blast-Furnace Practice," contributed by Mr. Fred Clements at the May Meeting of the Iron and Steel Institute in 1920, and published in the *Journal* of the Institute. This paper gave copious data, not only of the Park Gate furnace, but of a large number of other British blast-furnaces.

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[1] For this description the Council are indebted to *The Engineer* (September 1, 1922).

The principal dimensions of furnaces Nos. 1 and 2 are: Hearth diameter, 11 ft.; bosh diameter, 18 ft. 6 in.; stock line diameter, 13 ft.; and height, 70 ft. The dimensions of No. 3 furnace are as follows: Height, 70 ft.; hearth diameter, 11 ft.; bosh diameter, 20 ft.; stock line diameter, 13 ft. The blast pressure employed is 6½ lbs. per square inch, and the temperature averages 1020° F. There are eight 5¼ in. tuyeres and two 3¾ in. tuyeres. The charge consists of a mixture of raw Lincolnshire, Leicestershire and Northamptonshire ores, averaging 32 per cent. of iron, and containing considerable moisture which during the winter months may amount to as much as 25 per cent. The ores possess, however, the advantage of being self-fluxing. As delivered they contain approximately 25 per cent. of lumps, 35 per cent. of medium, and 40 per cent. of fines. South Yorkshire coke, derived mainly from the Staveley coke-ovens, is used in the proportion of 28 cwt. per ton of pig iron produced—equivalent to 23 cwt. of carbon.

With a burthen of this nature it will readily be understood that special care is necessary to secure satisfactory distribution. Skip charging has been adopted, the skips being raised on a double track incline, and the charge dumped on to a revolving stock distributor. The furnace top is equipped with a double bell. The capacity of the skips is 30 cwt. of ore, or 12½ cwt. of coke. Every stage of hoisting, tipping, rotating the hopper and raising and lowering the bell is faithfully recorded by an indicator in the control house, the operator having before him a model of the furnace top and being able to control with ease and accuracy the whole sequence of operations and stock distribution. The system, both of control and of the furnace top itself, has been devised and patented by Mr. Clements.

The blast is furnished by two gas-driven blowing engines, designed by the Snow Pump Company, Buffalo, N.Y., each capable of delivering 25,000 cubic feet of air per minute at 8 lbs. pressure per square inch, and three double-acting gas-driven engines of the Körting type. A double-acting steam-driven blowing engine is installed as a stand-by.

The gases from the furnaces issue at a temperature varying from 300° to 400°, and enter a dust catcher, 25 ft. internal diameter and 40 ft. high, where they impinge on a large steel cone, thereby undergoing a sharp change of direction and a considerable fall in velocity. For use under the boilers they undergo no further cleaning than is involved by their traversing the above chamber and the ordinary baffling of the gas main system. For use in the gas engines they are first thoroughly washed in water spray saturator towers, and finally passed through a Theisen cleaner, where their dust content is reduced to 0·02 gramme per cubic metre. Of the blast-furnace gases evolved, 35 per cent. is used in the stoves and 50 per cent. is burned under boilers. The boiler plant consists of a battery of nine Babcock-Wilcox boilers, generating steam at 160 lbs. per square inch. A further battery is in course of construction, provision being made for firing the new boilers, either with blast-furnace gas or, if for any reason the supply should fail, with powdered coal. Superheating is carried out to a moderate extent, and the steam raised is used for various purposes in and about the works. The exhaust from the mill engines is collected and used in mixed pressure turbines, which provide for the electrical power requirements of the works. The remaining 15 per cent. of blast-furnace gas—or, allowing for waste, 14 per cent.—is used in the gas engines. The pig iron is taken, in 25-ton capacity ladles, to the steelworks, where it is tipped into the metal mixer. The slag is run into 8-ton Dewhurst tipping ladles.

Open-Hearth Plant.

Open-hearth steel has been made at Park Gate since 1888, the original plant having consisted of two 25-ton hand-charged basic open-hearth steel furnaces. Later, an acid-lined furnace was added, but the present plant consists solely of basic steel furnaces, and the skill displayed in its manufacture has gone far to eradicate the former prejudices in favour of acid steel, the manufacture of which was discontinued in 1917.

The present plant is very extensive and thoroughly up to date. It consists of a 75-ton tilting furnace—which was originally a 200-ton metal mixer, but has been ingeniously "converted"—three 60-ton fixed furnaces, and seven 50-ton fixed furnaces, the aggregate capacity of the plant being thus little short of 6000 tons per week. There is also a 10-ton Greaves Etchells electric furnace, taking hot metal from the open-hearth furnaces for further treatment.

The dimensions of a typical 60-ton furnace are given in minute detail, together with logs of the working of a charge, in a paper by Mr. Fred Clements, on Siemens open-hearth practice, read at the May meeting of the Iron and Steel Institute this year. The main features are as follows :

Distance between port blocks	36 ft.
Width between walls	12 ft.
Gas port	16 in. by 16 in.
Gas port incline	1 in 3 ft. 6 in.
Gas chequers	12 ft. by 8 ft. 3 in. by 12 ft. 4½ in.
Gas chequers, volume	1225 cubic feet.
Air port incline	1 in 3 ft. 6 in.
Air chequers	12 ft. by 11 ft. 6 in. by 13 ft. 1½ in.
Air chequers, volume	1810 cubic feet.

These dimensions refer to furnace "M."

The gas valves are of the water-sealed reverse modified Wailes type, the air valves being of the dry type, with double-seated mushroom valves. The valves are all easily operated by hand through reduction gear, ball bearings being used throughout.

The charges worked average 50 per cent. scrap, charged by Wellman ground type charging machines, and 50 per cent. mixer metal, this being added after the scrap has been partly melted. The mixer practice is of considerable interest. The mixer is of 400 tons capacity, gas fired by its own battery of modified Dawson producers, with their accessory coal-handling and storage plant. It is of the active type, and, in addition to the ordinary desiliconisation and desulphurisation which occurs, a considerable proportion of manganese present in the pig iron slags out, leaving approximately 0·6 per cent. in the molten metal. The slag produced averages 1 cwt. per ton of pig iron passed through the mixer, and as this slag contains from 20 to 24 per cent. of MnO, it is used in lieu of manganese ore in the blast-furnaces, where it is again reduced in the pig, thus forming a cycle of operations which obviates the use of manganese ore in the burden, while affording a more steady and constant source of the manganese required in the pig iron, and hence in the mixer metal and eventually in the open-hearth furnace bath. It will be recalled that during the war the German steel-makers were driven for lack of manganese ore to adopt a similar cycle of operations, and that manganiferous slag, both from old ferro-manganese furnace slag tips and from mixers, was freely used to remedy the deficiency. The following analysis of the mixer slag in question may be regarded as typical :

Analysis of Mixer Slag.

Silica	32·0 to 34·0
Alumina	7·0 to 9·0
Lime	34·0 to 38·0
Magnesia	3·0 to 6·0
Sulphur	0·03 to 0·07
Manganese oxide	20·0 to 24·0
Iron	2·5

Limestone and Gellivara ore are added to the molten metal in the mixer to form this slag.

Producer-gas for the open-hearth furnaces is supplied by a battery of twenty-six Dawson type steam-blown producers, 7 ft. internal diameter, and capable of gasifying 8 cwt. of coal each per hour. To some of these producers steam-blown "P.G." poking holes have been provided. These holes, by the ingenious employment of a steam screen, enable poking and inspection to be carried out without the gases escaping.

An electrically propelled ladle carriage has been installed to serve the 75-ton tilting furnace, and the intention is to equip the whole of the open-hearth furnaces with similar carriages. Stripping is effected by three 25-ton high-speed overhead cranes driven electrically. A Wellman electric ingot stripper has been added to deal with stickers.

The ingots are machine-charged to the mill reheating furnaces, which are gas fired and supplied with air regenerators.

ROLLING MILL PLANT.

The rolling mill plant comprises a large 39 in. plate mill, a 38 in. billet mill, a 36 in. slab mill, all two high ; a three-high plate mill, rolling plates up to 35 ft. long by 5 ft. 8 in. wide ; a two-high 24 in. finishing mill ; a two-high 24 in. sheet mill ; a two-high 24 in. section mill ; and 18 in. and 10 in. two-high section mills. The particulars of the mills are described below :

	Slab Mill.	*Billet Mill.*
Size of mill	36 in. diameter	38 in. diameter
Engine	Two-cylinder, 50 in. by 60 in., reversing	Three-cylinder, 40 in. by 48 in., reversing
Size of product	36 in. by 10 in.	10 in. by 10 in. to 2 in. by 2 in.
Output per week, finished make	3000 tons	1400 tons

No. 1 Mill.

Size of mill—	
Large rolls	39 in. by 12 ft.
Hard rolls	30½ in. by 8 ft.
Engine	Two-cylinder, 50 in. by 60 in., reversing
Thickness of plates rolled	¼ in. to 2½ in.
Maximum weight	6 tons
Maximum length and width	60 ft. and 11 ft. 6 in.
Output per week, finished make	1000 tons

No. 2 Mill.

Size of mill—	
Top roll	28 in. diameter by 6 ft. 6 in.
Middle roll	18 in. diameter by 6 ft. 6 in.
Bottom roll	28 in. diameter by 6 ft. 6 in.
Engine	Single-cylinder, 34 in. by 48 in., continuous, 60 r.p.m.
Fly-wheel	38 tons
Thickness of plates rolled	$\frac{3}{16}$ in. to ½ in.
Maximum length and width	35 ft. and 5 ft. 8 in.
Output per week, finished make	700 tons

No. 3 Mill.

Size of mill—	
Finishing rolls	24 in. by 5 ft. 6 in.
Chequer rolls	24 in. by 4 ft. 6 in.
Engine	Single-cylinder, 28 in. by 42 in. continuous, 60 r.p.m.
Fly-wheel	38 tons
Thickness of plates rolled—	
Plain	⅛ in. to ¼ in.
Chequers	¼ in. to ½ in.
Maximum length and width—	
Plain	20 ft. and 5 ft.
Chequers	24 ft. and 4 ft.
Output per week, finished make	150 tons

No. 4 Mill.

Size of mill	24 in. by 5 ft.
Engine	Single-cylinder, 24 in. by 48 in.
Fly-wheel	38 tons
Thickness of sheets rolled	16 G. to $\frac{3}{16}$ in.
Maximum length and width	12 ft. and 4 ft. 6 in.
Output per week, finished make	150 tons

24 *in. Section Mill.*

Size of mill	24 in.
Sections rolled	All British standard joists and channels from 10 in. by 5 in., 10 in. by 3½ in. downwards; 9 in. to 4 in. rounds; 6 in. by 6 in. angles, &c.
Engine	Three-cylinder, 36 in. by 48 in., reversing
Output per week, finished make	35 tons

18 *in. Section Mill.*

Size of mill	18 in.
Sections rolled	From 4 in. to 2 in. rounds, 3¼ in. by 3¼ in. to 2 in. by 2 in. angles, 3½ in. by 3½ in. to 2 in. by 2 in. tees
Motor	250 horse-power A.C.
Revolutions of rolls	80 per minute
Output per shift, finished make	35 tons

10 *in. Section Mill.*

Size of mill	10 in.
Sections rolled	From 1⅞ in. to ½ in. rounds, 1¼ in. to ½ in. hexagons
Motor	500 horse-power D.C.
Revolutions of rolls	150 to 250 per minute
Output per shift, finished make	25 tons

The 24 in. section mill, which is typical of Park Gate rolling-mill practice, may be described in greater detail.

It has been installed to provide larger sections than the company was able formerly to supply. All British standard sections are rolled; from 10 by 5 joists, 10 by 3½ channels, 6 by 6 and 8 by 4 angles, 9 in. diameter rounds, &c., downwards. The mill will have an average output of about 1200 tons of finished sections, or rather more in favourable circumstances. A three-cylinder high-pressure steam engine, 36 in. diameter by 48 in. stroke, equipped with Joy's valve gear, provides the motive power. This engine was supplied by Markham & Co., Limited, Chesterfield. The exhaust is discharged into the low-pressure steam collecting main, and used in the mixed-pressure turbo-generator plant. The drive from the engine is direct to the bottom roll and through gear to the top roll, the length of the helical teeth being 4 ft. 6½ in. The gear is enclosed in an oil-tight and dust-proof casing, and the bearings are lubricated by an oil pump system.

The mill consists of three stands of rolls—roughing, forming, and finishing—and all rolls are at fixed centres. The roughing rolls take a 10 in. by 10 in. billet, and it is chiefly out of this size that the various sections are produced in lengths up to 200 ft. On one side of the roughing rolls an adjuster is installed, which passes the billet from one reducing hole to the next, whilst on the other side a manipulator is placed to turn over the billet for the next pass. Both the manipulator and adjuster are quick working by hydraulic power, and the cylinders and gear are arranged overhead, thus placing all working parts out of the way from scale, &c., and making these parts very accessible for repairs. On the one side a set of skids conveys the bar from roll to roll. Each stand of rolls is equipped with its own fixed roller gear tables, the peripheral speed of the rollers being about 650 ft. per minute. The drive for all roller gear from the motors, which are controlled by contactors, is through worm reduction gear, totally enclosed and running in oil baths. All mitre wheels driving rollers are enclosed in a gear case, and the tips of the teeth dip into an oil bath. All bearings for rollers are ring oil lubricated.

A 72 in. hot saw, driven by a 200 horse-power alternating-current motor, cuts up the various sections into lengths required. The peripheral speed of the blade is 15,250 ft. per minute. The feed is by means of hydraulic power. From the hot saw the material passes to the cooling bank, which is equipped with a double set of skids. Bars up to 60 ft. long can be dealt with on this bank. The stock banks are equipped with cold saw and cold straightening machines, and also laying-out racks for inspection purposes.

The billets are conveyed to the mill furnaces by means of an overhead crane equipped with a special slinging attachment. They are placed upon the skids of the reheating furnaces by the crane, and are fed along the furnace hearth by a hydraulic pusher. The furnaces are of the continuous reheating type, fitted with a three-arch roof, in which the air only is preheated. They are wide enough to take a billet 10 ft. long, and were designed and built by the Wellman-Smith-Owen Engineering Corporation, Limited. Four gas-producers provide the gas necessary for the reheating of the billets in the furnace. All the electrical and hydraulic controls are housed on overhead platforms, from which the operator has an uninterrupted view. The quick changing of rolls is effected by having spare sets of housings, ready fitted up with rolls and guides, &c. These are picked up by an overhead crane and placed into position.

Power House.

The electrical power plant consists of one 3000-kilowatt turbo-generator and two 1000-kilowatt turbo-generators. The former generates sufficient current for the whole works, and the two 1000-kilowatt machines are stand-bys. It was built by Metropolitan-Vickers, Limited, and consists of a Westinghouse Rateau mixed-pressure impulse turbine, direct coupled to a Westinghouse totally enclosed turbo type alternator. Alternating current is generated at 3000 volts, 50 periods, three-phase, 0·8 power factor at normal full load.

The condensing plant consists of a Mirrlees-Leblanc multiple jet condenser, with rotary air and extraction pumps. Natural draught cooling towers are employed.

The alternating current is converted by transformers and rotary converters to direct current at 220 volts, this being the voltage used almost throughout the whole works plant. Part of the alternating current is used direct by some of the plant.

McCONWAY CENTRIFUGALLY CAST STEEL.

The chief claim of the McConway process for tyre blanks is the large saving in metal which it effects. Mr. McConway has, however, carried the process a step further, and claims to produce centrifugally cast rings which can thereafter be cut into standard billets, and these billets used for rolling merchant products. His view is that this process can be got down to such a cost that it will be possible to produce even the cheapest forms of rolled steel, *i.e.*, ferro-concrete bars, from centrifugally cast billets.

The chief element of the McConway process is a centrifugal hydraulic casting machine consisting of a cylinder in which the castings are made, a piston fitting into it, and a hydraulic cylinder. The ingot metal from the furnace is tapped in the ordinary way into a ladle, which is brought to the machine, and the metal tapped through the runner into the casting cylinder through the detachable casting head. During the process of feeding the metal the machine is rapidly rotating, the peripheral speed in the casting cylinder being approximately 65 feet per second. The effect is that the metal is immediately forced to the periphery of the cylinder, and forms a cylindrical or ring-shaped ingot.

The cylinder is fitted with a cast iron liner, and the piston is of steel with a cast iron face, so that the whole cylinder against which the metal is cast is lined with cast iron, there being also a cast iron liner on the detachable head. In the matrix at present in use the diameter of the cylinder inside the cast iron liner is 30 inches. In the forging-press operations, which follow next, the diameter is usually increased, say up to 38 inches, or less if desired, the diameter of the central hole as required being the governing factor.

The length of the casting cylinder is 12 inches. Immediately after the metal is poured into it the piston is slowly advanced, and the cylinder of metal by this means is compressed during the cooling from its initial length of 12 inches to about 10½ inches. The whole process takes from 15 to 17 minutes. Approximately two-thirds of this time is taken up with casting, centrifugalising, and solidifying the cast, and the other third in removing it to the soaking-pit.

Hydraulic End.—The other end of the press consists of an ordinary hydraulic cylinder, which through its piston and rod operates the casting cylinder piston. A feature, however, of the invention, and a mechanical contrivance which has rendered the process possible, is the stuffing box. The great difficulty arose in getting hydraulic pressure into a cylinder rotating at this speed. The solution was the stationary hydraulic pipe, leading through the stuffing box on the outer end of the hydraulic cylinder and revolving in the pipe end, as on a nipple; orifice, 0·11-inch diameter. The usual water pressure is 500 lbs. per square inch, but pressures up to 1200 and 1400 lbs. have been employed.

The machine has given every satisfaction from a mechanical point of view in the casting of the centrifugal cylinders. Cast iron liners have been found to be the most suitable material with which to line the casting cylinder, and owing to the shrinkage of cast steel of approximately $\frac{1}{4}$ inch to the foot, there is, of course, no difficulty about ejecting the cylindrical ingot of metal when cast.

After being ejected from the press, the ingot is taken to a soaking-pit and then finished under an ordinary hydraulic press, one of 2000 tons being at present used for this purpose. It is then still further forged as may be necessary.

It follows that in this centrifugal casting process the metal at the periphery of the ingot is exceedingly dense and free from slag inclusions. The slag, being lighter, concentrates in the inside circumference of the casting, and it has been found advantageous to broach the hole in the " cheese " just before the last pass in pressing. A very light cut will remove practically all the slag inclusions. The further treatment of the ingot, therefore, which has previously been kept in a soaking-pit and brought again to a forging heat, includes this broaching of the centre core.

The chief claim of the process is, of course, the reduction in discard, which, as all steel-makers know, is a very large one when figured from ingot weight to weight of finished product, either in tyres, rails, or bars. The metal obtained is also very homogeneous and free from segregation and slag inclusions.

OBITUARY.

Richard Akerman, Honorary Member, died on February 23, 1922. He was born in 1837 in Stockholm, where his father, Joachim Akerman, was professor at the Technical University. In 1851 he entered the high school in Vesteras, and in 1855 the University of Upsala, from which he graduated as a mining engineer in 1860. He then entered the service of the Department of Commerce and graduated from the mining academy at Falun in 1862. The next year he was accepted as a student in the metallurgical section of "Jernkontoret," and in 1864 he was made an assistant in the same section. Thus began the co-operation with the Jernkontoret which was to continue for so many years. He rendered valuable assistance to Professor V. Eggertz in the preliminary work of preparing a handbook on blast-furnace practice, and also prepared a complete index to the *Jernkontorets Annaler*, covering the period 1817–1864. In 1865 he began a series of lectures on the metallurgy of iron at the mining academy at Falun, and in 1869 he was appointed instructor of mining and metallurgy at the Technical University, to which institution the higher education in mining engineering was transferred at that time. His career as a teacher of mining and metallurgy lasted until 1891. In 1877 he was appointed assistant professor, in 1883 acting professor, and in the same year dean of the mining college. In 1874 he was instructed by the Government to inspect the mining schools in Filipstad and Falun.

During 1866–1867 he studied the iron industries of this country, United States, France, and Austria. In 1868 he visited the steelworks in Upper Silesia, the Rhine Province, and Westphalia. In the same year he was appointed editor of the metallurgical section of the *Jernkontorets Annaler*, and from that time he was a constant contributor to the proceedings of that Society. In 1872 he served as a member of the Swedish Committee at the exhibition at Copenhagen, and also acted as judge. He received similar commissions in connection with the world expositions at Vienna in 1873, Philadelphia in 1876, and Paris in 1878. In 1891 he accepted the position of general manager and chief of the Bureau of Commerce, a position which he held until 1905. During that time he carried out many important public missions. He was appointed chairman of the committee for Sweden's participation in the World's Fair at Chicago, 1893; chairman or member of several committees connected with the Fairs in Stockholm in 1897, Paris 1900, and St. Louis 1904. In 1899 he was appointed chairman of the conference for international investigation of hydrography and biology of the waters around Norway, the North Sea, and the Baltic. On the termination of his services to the Bureau of Commerce he was appointed chairman of the Committee of Industrial Protection, and served in that capacity until 1909. He continued to serve the Technical University as a member of the Board from 1890 to 1908. In spite of his other activities he found time to act as librarian of the Technical University from 1869 to 1874, and as a director of the Stora Kopperbergs Bergslag from 1874 to 1876. In 1901 he became a director of the Stora Kopperbergs Bergslags Aktiebolag; in 1911 its vice-chairman; and in 1915 chairman of the Board of Directors, which office he held until 1917. He was also chairman of the Board of Directors of the Stockholm-Vasteras Bergslagens Railway from 1899 to 1917. He was one of the trustees of the Nobel Institute from 1902 and its vice-chairman from 1908 until his death. From 1894 to 1897 he was vice-chairman of the Board of the Technical University in Stockholm. He was the recipient of numerous foreign orders and was an honorary member of a number of leading technical societies in Sweden, United States and Russia. He was elected an honorary member of the Iron and Steel Institute in 1875, and in 1885 he was awarded the Bessemer Gold Medal for his services in connection with the development of the metallurgy of iron and steel. He took great interest in the activities of the Institute and acted for a number of years in the capacity of Foreign Contributor. In 1898, when the Institute visited Stockholm, he served on the Reception Committee, and was largely responsible for the excellence of the arrangements made whereby the success of the meeting was assured. He contributed the following papers to the proceedings of the Institute:

"The Generation of Heat during the Bessemer Process," 1872.
"The most Recent Advances in the Manufacture of Iron and Steel as Illustrated by the Paris Exhibition," 1878.
"Hardening Iron and Steel, its Causes and Effects," 1879.
"Caspersson's Converter-Ladle," 1880.
"The Development of the Swedish Iron Industry," 1898.

Herman Victor Hubert died on September 30, 1922. He was born at Liége in 1849, and after originally following a course of philosophy and literature, entered the School of Mines in 1867. He was appointed engineer on the mining staff in 1872, and whilst serving at Mons continued his studies in physical science and mathematics. In 1889 he was appointed Director of Mines in the Liége district, and in 1905 he became Inspector-General of Mines in Belgium. He was a Commander of the Order of the British Empire, and was also the recipient of several foreign orders. He was a member of numerous technical societies, and was elected a member of the Iron and Steel

Institute in 1906. He contributed the following papers to the proceedings of the Institute:

- "The Design of Blast-Furnace Gas-Engines in Belgium," 1906.
- "Present Methods of Testing, with Special Reference to the Work of the International Testing Association," 1913.
- "Recent Progress in the Design of Large Blast-Furnace Gas-Engines with Special Reference to Belgian Practice," 1915.

Sir RICHARD VASSAR-SMITH, Bart., died on August 2, 1922. He was born in 1843 and was educated at the College School, Gloucester. He joined his father's business of general agents for the Great Western Railway, becoming head of the firm in 1870. Later he became associated with the Gloucester Railway Carriage Co. and the Port Talbot Steel Co. He was also a director of Messrs. Baldwins, Ltd., British Mannesmann Tube Co.. Brymbo Steel Co., Taylor's Navigation Steam Coal Co., and Lloyd's Bank. In 1917 he received a baronetcy in recognition of the services which he rendered to the Government during the war. He was elected a member of the Iron and Steel Institute in 1907.

MARMADUKE WARDLOW died on October 5, 1922, at the age of fifty-eight. He was head of the firm of S. and C. Wardlow, crucible steel manufacturers of Portobello Steelworks, Sheffield, and Congress Works, Oughtibridge. He was the only son of the late Mr. Charles Wardlow, who with his brother Samuel founded the firm in 1883. When twenty-one years of age he entered the firm as partner, and became sole proprietor in 1892. He had been a member of the Cutlers' Company since 1907, and last year filled the position of Master Cutler. He was elected a member of the Iron and Steel Institute in 1893.

WILLIAM EDWARD WALKER died on November 9, 1922, at the age of seventy-three. He was born at Wigton, and after his early education at St. Bees, he served his time as mining engineer with the late Mr. William Davidson, Lord Leconfield's agent, at Whitehaven. Soon after the completion of his training, he became Secretary and Engineer of the Mowbray Iron Ore Co., and was afterwards concerned in the formation of several mining companies. He was Managing Director of the Ullcoats Mining Company for some years, and was for many years Director of the Whitehaven Hæmatite Iron and Steel Co. Mr. Walker also took a prominent part in the schemes for the development of other minerals, and his long experience caused him to be recognised as one of the leading authorities in Cumberland on metalliferous mining. He was elected a member of the Iron and Steel Institute in 1888.

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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In the preparation of these Notes the Editor has been assisted by L. P. SIDNEY, Assistant Secretary, and others.

IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—*GEOGRAPHICAL DISTRIBUTION OF ORES.*

(Arranged in alphabetical order under Countries.)

Australia.—D. Baker, *The Development of the Iron and Steel Industry in Australia* (Paper read before the American Iron and Steel Institute, May 26, 1922, 40 pp.). In Australia all the natural conditions exist which are favourable to the development of an iron and steel industry. The following is an account of the ore deposits and resources of the various States of the Commonwealth.

Western Australia.—The most important deposits in this State are those of Koolan and Cockatoo Islands in the Yampi Sound. On Koolan Island the main deposit stands out abruptly above high-water level to a height, in places, of 600 feet. It has been reported by the State mining engineer that the deposit has a length of 300 chains and an average width at the base of 100 feet. There are estimated to be 68,850,000 tons of iron averaging about 65 per cent. iron, 6 per cent. silica, and 0·06 per cent. phosphorus, and a trace of titanium oxide. On the northern end of the island there is another deposit estimated to contain 7,800,000 tons, averaging 66 per cent. iron, 5 per cent. silica, 0·04 per cent. phosphorus, and 0·35 per cent. titanium oxide. On Cockatoo Island there is a deposit of hæmatite outcropping for a length of 110 chains up to 300 feet in height and about 130 feet in width. The estimated tonnage available above high-water level is 13,850,000 tons, averaging 68 per cent. iron and 2 per cent. silica. Another deposit on the northern end of the island is estimated to contain 7 million tons of iron ore. Other deposits are widely distributed in Western Australia, but some of the richest and most extensive are valueless on account of their geographical position.

South Australia.—The ironstone deposits in this State are very numerous, but the only ones that have been extensively worked are the Iron Knob and Iron Monarch deposits, owned by the Broken Hill Proprietary Company. These deposits originally supplied flux to the lead smelters at Port Pirie, but are now utilised for the supply of iron ore to the company's blast-furnaces at Newcastle, New South Wales. On the Iron Monarch and Iron Knob, on the western shore of Spencer's Gulf, South Australia, there exists a large deposit of iron ore estimated to amount to at least 21 million tons. A later Geological Survey report puts the estimated reserves at 130 million tons, and further exploration by the company has proved two more valuable deposits, which have been named Iron Prince and Iron Baron.

In 1873 a small charcoal blast-furnace was erected near Mount Jagger, about eleven miles north of Victor Harbour, and ore was obtained from an extensive deposit of magnetite which caps the summit of Mount Jagger. Owing to the lack of skilled labour the operations were not successful.

Victoria.—About 1875 a small experimental blast-furnace was erected at Lal Lal near Ballarat, to work an iron ore deposit there, estimated to contain 750,000 tons of ore, with 68 to 70 per cent. FeO, 16 per cent. silica, and a trace of phosphorus. The ore forms a crust upon the older rocks in this locality. A small quantity of pig iron was produced, but the enterprise was soon abandoned. Deposits of hæmatite occur at Nowa Nowa, with which are associated magnetite and specular iron. Other deposits are known to exist in many places, but little is known about them.

Queensland.—Enormous deposits of specular iron, hæmatite, and magnetite have been surveyed in the Cloncurry districts. One of them, Mount Leviathan, is about 200 feet high and a quarter of a mile diameter at its base. The geographical position is considered to cause it to be absolutely valueless at present. The Mount Biggendon district also has high-grade iron deposits from which bar iron of good quality has been produced by the Maryborough iron-foundries. The estimated quantity of ore available here is 500,000 tons. During the war a Royal Commission was appointed by the Queensland Government to inquire into the advisability of establishing State iron and steel works. This State has a greater mileage of railways than any other (5287 miles of Government lines open for traffic and 428 miles under construction in 1918). It was considered that after the war there would be a great influx of people to Australia, leading to increased land settlement, especially in Queensland, and railway development would be stimulated. The Commissioners strongly recommended that the erection of a furnace with a capacity of smelting 150 tons of ore per day be immediately proceeded with, with by-product coke-ovens and mine equipment. A site was chosen and work was begun, but owing to the prevailing business depression it has been brought to a standstill before the erection of the furnace was started.

New South Wales.—The iron ore deposits in this State are numerous but scattered in their occurrence. A summary of them is given by J. B. Jaquet in a report to the Geological Survey of New South Wales in 1901. The two most important are those of Cadia with an estimated quantity of 39 million tons of specular hæmatite, magnetite, and carbonate ore, and Carcoar with about 3 million tons of hæmatite and brown ore. The total reserves of iron ore in the State are estimated at upwards of 53 million tons.

Tasmania.—A report of the Geological Survey of Tasmania, published in 1919, places the total iron ore resources of the island at about 42 million tons, the largest of which occur in the districts of Long Plain (20 million tons) and Blythe River (17 million tons). The iron content varies from 46 to 68·7, the silica from 1·6 to 34·2, and the phosphorus from 0·04 to 0·09 per cent. It is considered that on the whole the ore is too siliceous to be used as a commercial iron ore. In the Beaconsfield district a deposit of chromiferous ore exists, for the working of which a company was formed in 1872. Works were erected and a small blast-furnace was built. Several thousand tons of pig iron were smelted, the product containing 2 to 10 per cent. of chromium, and it was used by the Melbourne iron-founders for making battery shoes and dies, but on account of the difficulty of smelting ore containing 5 per cent. of chromium, and the irregularity of the product, the operations were not a financial success and the works were closed about 1877.

R. L. Jack, *The Iron Ore Resources of South Australia* (Geological Survey of South Australia, 1922, Bulletin No. 9). The individual deposits are described in detail with plans and charts. The outstanding deposits are the Iron Knob and Iron Monarch, and the Iron Prince and Iron Baron, in the Middleback Range, estimated to have ore reserves above the level of the surrounding country of 133,000,000 and 32,000,000 tons. Portions of the Iron Monarch deposit are highly manganiferous and, owing to the demand of the furnaces for ore yielding less than 1 per cent. manganese in the pig iron, this has to be met by blending with the non-manganiferous portions of the ore bodies. The deposits of Middleback are controlled by the Broken Hill Proprietary Company.

Canada.—G. C. Mackenzie, *Canada's Iron Ore Problem* (Iron and Steel of Canada, August 1922, vol. 5, pp. 136–139). The question of the beneficiation of Ontario iron ores is discussed. At present there is in Ontario no known deposit of merchantable iron ore, the development of which would be remunerative, but there are large bodies of low grade magnetite and siderite ores which can be beneficiated to a merchantable grade. The utilisation of the low grade hæmatites and titaniferous magnetites is doubtful, as the beneficiation of these ores has not yet reached a successful stage. There are only two concentration processes which merit attention, magnetic separation and calcining of siderites.

China.—H. Murakami, *Geology of the An-Shan Iron Mine District, South Manchuria* (Report published by the South Manchuria Railway

Co., Dairen, 1922). The district described in the report is confined to the territory prospected by the South Manchuria Railway Co., 56 miles south of Mukden and 193 miles north of Dairen. The Russians, when laying the railway from Harbin to Port Arthur, were unaware of the existence of the An-Shan iron belt, in spite of the fact that the railway crosses the middle of it. During the war the necessity for a near supply of ore in Japan was recognised, and in 1919 two blast-furnaces, with a capacity of 250 tons per day each, were completed in An-Shan. The district is sixty kilometres wide and abounds in iron although not of high grade. The ores occur in pre-Cambrian hæmatite-quartz schist and are unconformably overlain by Cambrian beds. The iron-bearing rock is an intimate mixture of hæmatite and crystalline quartz, generally containing less than 40 per cent. of iron. A limited amount of ore has been enriched by natural processes so as to run over 60 per cent. of iron. On account of the limited amount of this better grade ore, experiments are being conducted in concentrating the primary ores. The ore formation is of enormous thickness. The iron ore of the An-Shan district has many points of similarity to that of the Lake Superior Region.

Cuba.—E. S. Murias, *Mineral Resources of Cuba* (Engineering and Mining Journal-Press, July 29, 1922, vol. 114, pp. 197–198). Iron ore, manganese ore, chromite and copper ore occur, but comparatively little is known about the mineral deposits. This is due mainly to defectiveness of the mining laws, political unrest, and lack of interest on the part of the government. Extensive deposits of limonite are found in the Province of Pinar del Rio, specularite in Havana (Isle of Pines), magnetite in Matanzas, limonite in Camaguey, and limonite and hæmatite on the northern and southern coasts, respectively, of Oriente. The deposits in this last province have been worked for years, and at present are being worked by a subsidiary of the Bethlehem Steel Co. For several years prior to 1914 about 1,500,000 tons were shipped to the United States. Ores from the southern coast run approximately 55 per cent. iron, 7 per cent. silica, 0·25 phosphorus and 0·5 sulphur; those from the northern shore are characterised by the presence of 1·98 per cent. nickel and chromium combined and a low phosphorus content, about 0·06 per cent. This ore undergoes a process of dehydration and nodulisation before it is shipped. The nodules run 55 per cent. iron, 15 per cent. alumina, and 4 per cent. silica. The indications of petroleum in Cuba are widespread.

Germany.—H. Haf, *The Iron Ore Deposits in North-Eastern Bavaria* (Stahl und Eisen, September 14, 1922, pp. 1417–1424). A large number of iron ore deposits exist in this region, many of which were worked from very early times, but since the middle of the nineteenth century the industry was no longer able to hold its own against the modern developments in districts more favourably situated as regards fuel. The ores are low grade, averaging about 35 per cent. iron, but samples from some small deposits of hæmatite show about 41 to 44 per cent. of iron, with 0·02 per cent. phosphorus. These ores may be regarded as a potential reserve for the German iron industry.

K. Hummel, *Hæmatite Deposits in the Devonian of the Kellerwald* (Zeitschrift für Praktische Geologie, May 1922, vol. 30, pp. 69–71). The Kellerwald is the natural continuation of the Dill basin with its ore fields. The prospects of renewing the working of an abandoned mine are discussed.

H. Haf, *The Spathic Iron Ore occurrence in a Mine near Lobenstein* (Zeitschrift für Praktische Geologie, May 1922, vol. 30, pp. 77–81).

India.—L. L. Fermor, *Mineral Resources of Bihar and Orissa* (Records of the Geological Survey of India, 1921, vol. 53, Part III., pp. 239–319). An account is given of the geology of the district, followed by a description of the mineral deposits. The province is very rich in minerals of economic value, especially coal, iron ore, and manganese ore. The annual output of coal in the war years averaged 11,551,000 tons, of iron ore 400,000 tons, and of manganese 7532 tons; since 1918 the production of manganese ore has reached the average production before the war of 32,000 tons yearly, the grade of the ore being 47·5 to 50 per cent. manganese. As a source of iron ore Bihar and Orissa is the most important province in India, the production in 1920 being 517,000 tons, out of a total for the whole of India of 558,000 tons. Other minerals reported on include bauxite, chromite, cobalt, graphite, magnesite, molybdenite, tungsten, and mica.

Japan.—H. Nishihara, *The Principal Mines of Japan* (Engineering and Mining Journal-Press, August 5, 1922, vol. 114, pp. 239–244). The author briefly describes the principal features of the geology, mineralogy, and production in 1917 of the more important metal mines of Japan.

Malay Peninsula.—*Iron Ore in the Malay Peninsula* (Engineering and Mining Journal-Press, September 16, 1922, vol. 114, p. 504). According to the annual report of J. B. Scrivenor, government geologist of the Federated Malay States, interest has been shown in the iron ore deposits of the Malay Peninsula, following the exploitation of a deposit on the Batu Pahat River, Johore. A large hæmatite deposit occurs at the north end of Gunong Panjang. It is reported that possibly about 2,000,000 tons of ore is available above surface drainage level and probably 4,500,000 tons within 100 feet below that level. Analyses of two samples of the ore are as follows:

	Per Cent.	Per Cent.
Iron	68·02	68·70
Sulphur . . .	0·03	0·013
Phosphorus . . .	0·07	0·086
Manganese . . .	0·60	0·45

Norway.—H. H. Smith, *Notes on the Skorovas Iron Pyrites Deposit, Norway* (Bulletin of the Institution of Mining and Metallurgy, October 1922, No. 217).

Philippine Islands.—*Mineral Industry of the Philippines* (Mining Journal, June 24, 1922, vol. 127, pp. 474–475). Probably the most important mineral deposits contained in the islands are those of iron ore, which have been examined in three different localities—at Bulacan, in the country about a hundred miles north of Manila; at Calambayanga, close to the coast in North Camarines; and at Surigao, near the northernmost point of the island of Mindanao. At the last-mentioned spot there is a deposit of lateritic iron ore resembling the Cuban deposits at Nipe Bay. The reserves are estimated at 500 million tons, and the ore is said to average 54·29 per cent. iron, 10·56 alumina, 1·04 silica, with traces of phosphorus and sulphur. In view of its importance, the deposit has been marked as a government reserve. The Calambayanga ore is almost pure hæmatite, averaging 64·14 per cent. iron. These ores were mined by the Japanese during the war, the output in 1919 being about 18,000 tons, but an export tax, equal to about 4s. per ton, stopped the trade when prices began to fall. The Bulacan deposits are in a mountainous region, and could only be developed by ropeway transmission. The ore is also high grade, with iron 62·54, phosphorus 0·052, and sulphur 0·02 per cent.

South America.—O. Wilson, *Mineral Earths and Clays of Latin America* (Chemical and Metallurgical Engineering, April 5, 12, 19, 1922, vol. 26, pp. 631–636, 697–700, 745–749). A series of articles describing the mineral resources of Latin America, and analysing the economic factors on which their development is dependent. The scarcity of good coking coal has hindered the development of the iron and steel industry. There are coal deposits in southern Brazil which can be used for industrial purposes when mixed with imported coal, Chile has extensive beds of coal, and Venezuela has deposits of unknown extent, but this is nearly all lignite and is too soft or friable for coking. Colombia, it is estimated, has billions of tons of coal, some of which is hard coal, and Peru is said to have several million tons of anthracite; but in the case of the former country the difficulties of transportation are such that the deposits can serve only local uses, and in Peru the cost of mining and haulage is so great that that country imports much more than it produces. Only in Mexico can domestic supplies of both coal and iron be utilised to establish an iron industry. In Chile the only serious attempt to establish a steel plant, using wood as fuel, ended in financial loss. In Brazil several attempts have been made, with the support of the Government, to establish plants for the production of steel with the aid of electricity derived from hydro-electric installations, but the cost has been found too high. The latest enterprise of this character is one promoted by Brazilian interests, which are now erecting at Ribeirao Preto, in the State of Sao Paulo, two blast-furnaces, with a daily capacity of 60 tons, two Bessemer converters, an electric furnace, and two bar mills. The iron countries of Latin America are Brazil, Cuba, Chile, Mexico, and Venezuela, with deposits of apparently little economic importance in Argentina, Uruguay, Peru, and Colombia. Brazil is the most important of all, and its fields may develop into the leading producing fields of the world. The Brazilian deposits of manganese are numerous and rich, and the possibilities for future production are most promising. The most important producing area is in Minas Geraes, near the iron deposits, and much of the ore is found in the Itabira formation. The only other country in South America that has shipped manganese in large quantities is Chile. Chromium is found in Brazil, Cuba, Guatemala, and Mexico, although production has not reached large proportions. Bolivia, Peru, and Argentina are producers of tungsten, the first-named being the most important. The most important supply of vanadium is found in the Department of Junin, in Peru.

Spain.—*Iron Ore Deposits in Granada, Spain* (Iron and Coal Trades Review, August 4, 1922, vol. 105, p. 150). An abstract is given of a report by two Spanish mining engineers on the possibility of working certain iron ore deposits in the province of Granada. The regions in question are Huétor-Santillán, Diezma, Colomera, Loja, and Algarinejo.

Sweden.—B. Kjellberg, *Utilising Iron Ores containing Vanadium* (Jernkontorets Annaler, 1921, vol. 76, pp. 147–151). Swedish magnetic iron ores containing appreciable amounts of vanadium also generally contain titanium. The ore is contained in a form such that after complete grinding the concentrate still holds up to 1·5 per cent. of vanadium and from 5 to 15 per cent. of titanium. Such ores are usually very low in phosphorus. With low titanium contents these ores can be charcoal smelted in electric blast-furnaces and both the vanadium and titanium are slagged out. These slags are sulphide-roasted for recovery of these metals.

Tasmania.—H. Lavers, *Notes on Tungsten, with particular Reference to King Island Scheelite Treatment and Assays of Low-Grade Material* (Australasian Institute of Mining and Metallurgy, Proceedings, September 30, 1921, No. 43, pp. 101–152). In Part I. of the paper the different ores of tungsten are described. Tungsten occurs in combination with other elements in eleven minerals, the principal of which are wolframite, containing tungsten tri-oxide in association with iron and manganese, and scheelite, with tungsten tri-oxide in combination with lime. The tungsten-bearing minerals ferberite and hubnerite belong to the wolframite series and contain varying proportions of iron and manganese. The compounds of tungsten, its metallurgy, and the preparation of pure tungsten metal and ferrotungsten, are described. Part II. of the paper deals with the particular method of treating the tungsten ores developed during the war on King Island in Bass Strait to the north-west of Tasmania. The scheelite bearing ore contains from 0·68 to 1 per cent. of tungsten tri-oxide, from which, by crushing, screening, and dressing on Wilfley tables, a 66 to 70 per cent. concentrate is obtained. For the six months ending March 31, 1920, 15,823 tons of ore were sent to the mill for treatment, averaging 0·67 per cent. of tungsten tri-oxide which produced 121 tons 7 cwt. of concentrate, averaging 69·6 per cent. of tungsten tri-oxide, representing a recovery of 79·5 per cent. Part III. of the paper deals with the methods of assaying the low-grade tungsten minerals. In the method in use in the mill, a solution of cinchonine is employed as the precipitant for WO_3, as this has been found to be superior to mercurous nitrate in the case of assaying impure and low-grade ores.

United States.—F. L. Nason, *The Importance of the Iron Ores of the Adirondack Region* (Paper read before the American Iron and Steel Institute, May 26, 1922, 40 pp.). The paper is supplementary to an earlier one by F. S. Witherbee, published in 1916 by the American Iron and Steel Institute, and gives details as to the magnitude of the deposits, the general grades of the ores, their treatment by magnetic separation, and the general costs of mining and concentrating. The total iron ore bearing area is approximately 10,000 square miles. One portion of this area, covering about 1500 square miles, contains titaniferous ore deposits, the Sanford Lake deposits being the only ones of economic size. About 70 to 100 million tons of ore have been proved, with a possible additional 186 millions. This ore can be treated to yield concentrates with 56 to 60 per cent. iron, 3 to 7 per cent. titanium, and 0·004 per cent. phosphorus. The remaining part of the area consists mainly of grey gneiss which contains large quantities of non-titaniferous iron ores capable of concentration. The total ore in sight in the whole area, including the Sanford Lake ores, is 186 million tons, and the total prospective reserves besides amount to about 1736 million tons. The grey gneiss ores yield concentrates containing 68 per cent. iron or over, with 0·004 to 0·2 per cent. phosphorus. The raw ores of Lake Sanford contain up to 12 per cent. titanium and 50 per cent. iron. The grey gneiss ores are magnetic, with iron ranging from 25 to 30 per cent., but they possess the almost unique characteristic that they are chemically pure. Even the leanest can be raised by magnetic concentration to the theoretical limit of iron in magnetite, namely 72·4 per cent.

Mineral Resources of the World.—O. R. Kuhn, *World's Iron Ore Resources* (Iron Age, July 27, 1922, vol. 110, pp. 211–215). The reeserves of iron ore in each country are shown, together with particulars of the average iron content and class of ore. The world's total reserve of known ore is estimated at 32 billion tons, equivalent to about 15,000 million tons of metallic iron, and the probable reserves of ore at 100 million tons.

Iron Ore: Summary as to the Present and Prospective Iron Ore Supplies of the World (Imperial Mineral Resources Bureau, London, 1922). Part 1 of this report gives a summary of information as to the present and prospective iron ore supplies of the United Kingdom. The most important section deals with the Jurassic ores of Cleveland, Lincoln, Leicester, Northampton, Rutland, and Oxfordshire. The carboniferous clayband and blackband ores, the hæmatites of Cumberland, and the other minor deposits, such as those of the Forest of Dean, North Wales, and Ireland are also dealt with. Complete statistics are given of the iron trade. Part 2 deals with British Africa, and contains information regarding the deposits in the Union of South Africa, Rhodesia, Swaziland, British East and Central Africa, Egypt and the Soudan, and British West Africa. Part 3 deals with British America and includes Canada, Newfoundland, British Guiana, and Trinidad. The section dealing with Canada is based on a special report to the Imperial Mineral Resources Bureau, and the two volumes issued in 1917 by the Canadian Department of Mines. A large section of Part 4 is devoted to the iron ores of the Indian Empire. The ores of Ceylon, Malay States, Borneo, Brunei and Sarawak, Hongkong, Mesopotamia, and Palestine are also described. Part 5 deals with Australia and New Zealand. The iron ore deposits of Europe and Foreign Africa are described in Part 6. The iron ore deposits of the United States, South America, Cuba, and the West Indies are dealt with in Part 7.

Part 8 deals with Foreign Asia and includes Arabia, China, French Indo-China, Japan, Korea and Formosa, Dutch East Indies, Persia, Philippines, Siam, Siberia, Tibet, Timor, Transcaucasia, Turkey-in-Asia, and New Caledonia.

Chromium Ore (Bulletin of the Imperial Institute, 1922, vol. 20, No. 1, pp. 112–114). A summary is given of recent information collected from various sources regarding the principal chromium ore deposits of the world.

Manganese Ores (Bulletin of the Imperial Institute, 1922, vol. 20, No. 2, pp. 245–250). A summary is given of recent information relating to the sources of manganese ores. At the present time India is the chief source of the ore and Brazil comes next. Russia now is almost negligible as a country of supply owing to the political condition.

Vanadium (Imperial Mineral Resources Bureau, Mineral Industry of the British Empire and Foreign Countries, London, 1922). The distribution of vanadium ore in the chief producing countries is shown, together with statistics of production and an outline of the metallurgy.

II.—*MINING OF ORES.*

History of Mining Metalliferous Ores.—H. H. Manchester, *An Illustrated History in Mining and Metallurgy* (Engineering and Mining Journal, September 2, 9, 16, 23, 1922, vol. 114, pp. 409–413, 447–450, 495–499, 545–548). The author outlines mining conditions in early Egypt, Greece, and Rome, the processes used in extracting and smelting ore in the Middle Ages, and the early practices of the Incas and Spaniards in sixteenth century America, as observed from drawings and writings.

III.—*PREPARATION OF ORES.*

Concentration of Iron Ore.—H. H. Wade, *Magnetic Log Washers in Iron Ore Concentration* (Engineering and Mining Journal-Press, May 6, 1922, vol. 113, pp. 769–771). Large tonnages of low grade hæmatite ore of a variety called " wash ore " are concentrated in Minnesota by use of specially designed log washers. By the addition of magnets to the bottom of the trough of an ordinary log washer it is possible to concentrate the finely crushed magnetite ores. Various types of magnetic washers are described.

Concentrating Magnetite Ore (Mining and Scientific Press, 1921, vol. 123, pp. 769–770). A description is given of a concentrating plant recently erected on the Mesabi Range, near Duluth, U.S.A. The Davis magnetic concentrator is used. The method of reducing the ore and the method of sintering is described.

Briquetting Iron Ore.—*Plant for Briquetting of Iron Ores* (Engineer, August 11, 1922, vol. 134, p. 149). A briquetting and calcining plant has recently been erected by Sutcliffe, Speakman & Co., at the Cockerill Works, Seraing, for the treatment of 150 tons of pyrites per day of twenty-four hours. No binding mixture of any kind is used, and the briquettes after pressing are calcined in a tunnel kiln. The general arrangement of the plant is shown.

REFRACTORY MATERIALS.

Magnesite.—*Magnesite Discovery in Nevada* (Mining Journal, September 2, 1922, vol. 138, p. 668). A massive deposit of magnesite in Nevada has recently been brought to the attention of the United States Geological Survey. The material has for some time been known as kaolin, but it is now stated to be in fact magnesite. It is porcelain white, fine-grained and massive, and is remarkably free from foreign material. It has the structureless appearance and conchoidal fracture that are generally characteristic of magnesite. The composition of the mineral is: silica 11·82, alumina and ferric oxide 0·94, lime 5·90, magnesia 36·40, carbon dioxide 43·45 per cent. The deposit is so large and readily accessible that it is likely to form a valuable source of magnesite.

Fire-Clays.—C. W. Parmelee, *Refractory Clays of Illinois* (Journal of American Ceramic Society, October 1922, vol. 5, pp. 685–692). A brief description of the geological occurrence of the fire-clay beds of Illinois, and the results of tests of samples which are typical of various areas.

Graphite.—*The Graphite Industry of Madagascar* (Bulletin of the Imperial Institute, 1922, vol. 20, No. 1, pp. 61–68). An account is given of the character of the graphite deposits of Madagascar, together with statistics of the industry. The graphite is of excellent quality, about 60 per cent. of the production being considered of crucible grade. The deposits are of great extent, and can be mined cheaply near the surface.

A. B. Parsons, *Milling Graphite at Stockertown, Pa.* (Engineering and Mining Journal, August 19, 1922, vol. 114, pp. 325–329). An illustrated description is given of the new plant of T. P. Kelly & Co. for the grinding and sizing of graphite.

Preparation, Properties, and Tests of Refractories.—A. G. Wikoff, *Manufacture of Fire-Clay Refractories* (Chemical and Metallurgical Engineering, September 6, 1922, vol. 27, pp. 505–509). The plant and layout of a model refractory manufacturing installation, near St. Louis, Missouri, to utilise the famous Cheltenham seam of plastic fire-clay, is described and illustrated. This clay and flint clay are the raw materials employed, the clay being obtained from mines some five miles distant. Flint clay of high grade is obtained from Owensville, about a hundred miles distant. As secondary raw materials, plastic clay grog, flint clay grog, and flint clay calcine are used. The mixtures vary with the purpose for which the final product is required. Mixtures for brick-making are mixed with water in a pug mill and passed to an auger machine, where they are forced through a rectangular die and emerge as a dense continuous column 9 inches wide and 4½ inches thick. It is wire cut into bricks, conveyed to Bonnot presses and pressed, dried in waste-heat driers by the waste heat from the kilns, and eventually burned in round down-draft periodic kilns, of which there are twenty of 36 feet diameter and one of 40 feet diameter. Very careful setting is required, as special shapes are incapable of supporting one another.

W. Steger, *Apparatus for the Determination of Deformation of Refractories under Load* (Berichte der Deutschen Keram. Gesellschaft, 1922, vol. 31). The author reviews previous methods of testing refractories by mechanical means and describes his apparatus, which is portable and independent of the furnace, for heating the specimens. The deformation is recorded automatically.

R. C. Purdy, *Standardisation of Refractories* (Chemical and Metallurgical Engineering, September 27, 1922, vol. 27, pp. 637–638). The industrial requirements for refractories have been steadily increasing in severity, and hitherto it has not, in the face of changing conditions, been feasible to form specifications or adopt standards. It is doubtful if, with present knowledge, even a satisfactory classification can be arrived at, and many so called standard tests do not check with operating results. Data on service conditions will require to be collected before any really satisfactory scheme of standardisation can be hoped for.

D. A. Jones, *Standardisation of the After-Contraction Test of Fire-Bricks* (Report of Refractory Materials Research Committee of the Institution of Gas Engineers, June 1922; Gas Journal, June 1922, vol. 158, pp. 840–844). The after-contraction tests of fire-bricks when made according to the standard specification have been found to give discordant results. It has been attempted to eliminate the error by the use of whole bricks for the test but without success, as the chief source of error is the dislocation of the surface of the brick after firing. Different bricks from the same batch show a difference in after-contraction due to uneven firing in the kiln during manufacture.

K. Endell, *The Testing of Silica Brick* (Journal of the American Ceramic Society, April 1922, vol. 5, pp. 209–218). The Steger load test apparatus was employed in the tests. Test cylinders, 50 millimetres high and 50 millimetres diameter, were cut out of standard burnt silica bricks and were heated for one and a half hours up to 1600° C. in a carbon resistance furnace. Pressure at 1 kilogramme per square centimetre was applied by means of a hollow carborundum rod. The relative amounts of quartz, cristobalite, and tridymite were determined from photomicrographs by measuring the area occupied by the quartz and silicate crystals and estimating the tridymite and cristobalite by difference. As the result the following specification for A1 silica brick is suggested: True specific gravity not to exceed 2·38; permanent linear expansion not to exceed 2 per cent. after heating to 1600° C. in one and a half hours, and holding at that temperature for half an hour. The amount of quartz and silicates as determined from the photomicrograph should not exceed 15 per cent.

E. Sieurin, F. Carlsson, and B. Kjellgren, *Determination of the Compressive Strength of Fire-Bricks at High Temperatures* (Berichte der Deutschen Keramischen Gesellschaft, 1922, vol. 3, pp. 53–64). To determine the compressive strength of fire-bricks at high temperatures, a mixture of one part of blue clay and four parts of fire-clay was ground until it passed a 250-mesh sieve. Part of the powder was burnt at cone 14 and crushed into grog. Equal parts of the grog and the fine clay were mixed and formed into 30-millimetre cubes and fired at cone 14. The refractoriness of the cubes under load was then determined, this being defined as the temperature at which the cube contracted 0·3 per cent. under a pressure of 2 kilogrammes per square centimetre after heating for two hours. Similar cubes containing varying percentages of silica, alumina, ferric oxides, lime, and magnesia were also examined. The minimum refractoriness under load occurred with 60 to 70 per cent. silica, and without load at 90 per cent. of silica. On increasing the alumina the refractoriness under load increased steadily up to 80 per cent. alumina, when the test-pieces failed suddenly. An increase of only 0·64 in the iron oxide reduced the refractoriness under load by 50° C. With further increase of iron oxide it diminished more slowly, remaining almost constant between 6 and 12 per cent. of iron oxide, after which a rapid loss of refractoriness occurred.

E. Sieurin and F. Carlsson, *Resistance Tests on Fire-Bricks under Loads at High Temperatures* (Journal of the American Ceramic Society, April 1922, vol. 5, pp. 170–180). The tests described were carried out at the laboratory of Höganäs Works in Sweden. Mixtures of fine ground china clay and ball clay with grog of the same materials were made into 3 centimetre cubes and subjected to a pressure of 2 kilogrammes per square centimetre at temperatures high enough to bring about a linear contraction of 0·3 per cent. in two hours. Definite quantities of silica, alumina, ferric oxide, lime, and magnesia were added, and both the deformation and the usual softening points were determined. Very small amounts of the oxides of iron, calcium, and magnesium considerably reduced the resistance to pressure. A minimum resistance was observed with silica contents beween 60 to 70 per cent., which does not correspond to the minimum softening point or melting point of clay silica mixtures. Additions of alumina increased the temperature required to deform the specimens, but with high alumina content mechanical failure due to lack of bonding material occurred.

R. M. Howe and W. R. Kerr, *Influence of Grind and Burn on the*

Characteristics of Silica Brick (Journal of the American Ceramic Society, April 1922, vol. 5, pp. 164–169). Finer grinding improves the appearance of the bricks and increases their strength somewhat, but not in a very marked degree. Tests show that a fifteen to twenty minutes' grind gives the best results, and the porosity is not appreciably affected by the time of grinding. The firing temperature is the principal factor governing the final strength and also the permanent residual expansion. The highest strength and the lowest expansion were obtained after firing to cone 19.

J. T. Robson, *The Influence of Heat on the Microscopic Properties of Silica in its different Mineral Forms* (Journal of the American Ceramic Society, October 1922, vol. 5, pp. 670–674). A study has been made of the effect of heat at cone 13 and cone 14 on the index of refractoriness of the four common forms of silica used in the ceramic industries. These mineral forms are sand, quartz, chalcedony, and French flint.

M. F. Peters, *Carborundum Brick* (Journal of the American Ceramic Society, April 1922, vol. 5, pp. 181–208). The author has studied carborundum-clay mixtures with reference to the relation between the proportioning and sizing of the constituents and the properties of the refractory as expressed by the tensile strength, the load test, the slagging, and the spalling tests. For good working conditions the amount of clay must suffice to cover the grains of carborundum. The resistance to spalling depends on the content of carborundum, the tensile strength, the coefficient of expansion, and the thermal conductivity of the clay.

W. A. Hull, *Thermal Conductivity of Refractories* (Paper read before the American Society for Testing Materials, June 1922: Chemical and Metallurgical Engineering, September 13, 1922, vol. 27, pp. 538–540). Differences in thermal conductivity between different brands or kinds of refractory materials, even if considerable, are relatively unimportant as regards the efficiency of an installation, as the conductivity of a wall is only one of the several factors affecting heat transmission, and a 10 per cent. difference in conductivity may only make a 2 to 5 per cent. difference in the heat flow through a wall. On the other hand such differences may in some cases, as in retorts and muffles, become an important factor. Most heat conductivity estimations are elaborate and tedious, and there is need for a standard method for making routine tests on these properties.

A. T. Green, *Thermal Conductivity of Refractory Materials at High Temperatures* (Gas Journal, 1922, vol. 158, pp. 844–852). In a report of the Refractory Materials Research Committee of the Institution of Gas Engineers the author gives a critical review of previous experimental work on the thermal conductivity of refractories, and describes the method of carrying out further experiments. The conductivity of the materials used was obtained by multiplying the diffusivity by the product of the specific heat and the apparent specific gravity of the material. The results obtained were lower by about one-half than those given by calorific methods, but thermal conductivity of silica and fire-brick materials increased with rise of temperature. The conductivity of magnesite was greater than that of fire-bricks at temperatures below 1000° C., but it decreased with rise of temperature. The variation of diffusivity with the temperature is shown, and it is suggested that the diffusivity is the best guide of the thermal efficiency of the material, while thermal conductivity is the important factor where insulating properties are required.

Y. Tadokoro, *Determinations of the Thermal Conductivity, Specific Heat, Density, and Thermal Expansion of Different Rocks and Refractory Materials* (Science Reports, Tohoku Imperial University, 1921, vol. 10, pp. 339–410). The report describes experiments made on 109 specimens of Japanese and Asian rocks and refractory materials. For the determination of the thermal conductivity the specimen is periodically heated and cooled, and the penetration of the temperature wave into its interior is measured, the diffusibility being calculated by means of Fourier's series. The method is troublesome though it gives accurate results. The measurement, however, becomes very simple if a pure sinusoidal source of heat can be obtained, and such an arrangement was satisfactorily devised, using a variable resistance in a plectrum form. The conductivity was found to increase with the content of magnesia, but decreases with that of silica lime and alumina. The densities are calculated from the coefficients of expansion.

E. E. Ayars, *Moulds for Magnesite, Chrome, and Silica Bricks* (Journal of the American Ceramic Society, February 1922, vol. 5, pp. 67–84). The various types of moulds for refractory bricks, the materials used, and practice in their manufacture are described. The determination of allowance for the shrinkage which occurs in burning the bricks is of prime importance, and the usual shrinkages to be allowed for with different materials, which are also influenced by the position in which the brick is set for firing, are stated.

P. S. Devereux, *A Review of Refractories* (Journal of the Birmingham Metallurgical Society, vol. 8, No. 2, pp. 52–64). The characteristics and properties of fire-bricks are discussed.

H. Winterton, *Foundry Refractories* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, September 21, 1922, vol. 26, pp. 236–238). The author discusses the applications of the various refractories used in foundry practice.

M. Boehm, *Noxious Effects of Saline Substances in Coal for Carbonisation* (Gas Journal, April 26, 1922, vol. 158, pp. 206–208). The active agents in corrosion of refractories used in carbonising plant are alkalies and chlorine. Particularly in tar stills the main destructive action is due to ammonium chloride.

P. Gilard, *Silica Bricks for Coke-Ovens* (Revue Universelle des Mines, June 15, 1922, vol. 13, Series 6, pp. 441–445). A summary of recent literature on the subject, from British and American sources.

A judgment has been delivered in the United States Circuit Court of Appeals which has the effect partly of invalidating the Davidson patent (June 1905, No. 792,822), covering certain refractory compounds for furnace linings. The claims were in respect of comminuting natural magnesite, oxide of iron and silica, fritting in a rotary kiln and again comminuting the frit. While the claim that silica played a useful part in the operation might have been held to be a patentable discovery it was not a novelty, as silica is present in all ordinary circumstances, while the use of a rotary kiln is only in the nature of a step which would be taken in the ordinary course by anyone familiar with refractory practice (Chemical and Metallurgical Engineering, July 5, 1922, vol. 27, pp. 20–21).

FUEL.

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I.—*CALORIFIC VALUE.*

Calorimetry.—E. Goutal, *On Observed Discrepancies in the Determination of Calorific Value and of Volatile Matter* (Liége Scientific Congress, 1922: Industrial Chemical Section, pp. 57–66; Revue Universelle des Mines, September 15, 1922, vol. 14, Series 6, pp. 467–476). The causes of erroneous estimations of calorific value are to be found in an incorrect water-equivalent, in inaccurate thermometer readings, in wrong manipulation or badly connected apparatus, and finally (a cause of frequent occurrence), in the accidental presence of combustible gases in the oxygen used. On the other hand, by avoiding these sources of error, the Mahler bomb method can invariably be relied upon to give accurate results. As regards the estimation of volatile matter, the following precautions must be introduced if results are to be trustworthy. The whole sample must pass through a sieve of not less than 250 mesh per square centimetre. A porcelain crucible should be used, in preference to a platinum one. The crucible should be protected from the direct action of the flame, and charcoal interposed to avoid oxidation. The temperature required should be reached gradually, in about half an hour, and maintained for a quarter of an hour. Finally the residual coke should be cooled and weighed in a tared crucible, and a watch-glass used during the operation of weighing.

Ignition Temperature of Coal.—R. W. Arms, *The Ignition Temperature of Coal* (Illinois University: Engineering Experiment Station, 1922, Bulletin 128). The author describes a series of experiments to determine the ignition temperature of coal. He points out that there is no definite temperature at which coal bursts into flame. The phenomenon of flame from coal is due to the combustion of volatile matter driven off from the coal, the character of such matter varying under different conditions; hence, the temperature at which the coal flames varies widely, and is dependent upon surrounding conditions.

The flaming temperature of a coal does not therefore serve as an indication of the ignition point.

Pulverised Coal.—*Pulverised Fuel under Steam Boilers* (Iron and Coal Trades Review, June 9, 1922, vol. 104, p. 858). The results are given of a number of tests on the firing of boilers which were carried out under the direction of the United States Government.

J. Blizard, *The Preparation, Transportation, and Combustion of Powdered Coal* (Department of Mines, Canada, 1921, Report 564). Discusses the appliances for the use of pulverised coal, the application of it in raising steam, the cost, and the dangers to be guarded against.

T. Wilson, *Powdered Coal and Blast-Furnace Gas at River Rouge* (Power, November 1, 1921, pp. 664–670). At the new power plant of the Ford Company at River Rouge four boiler units have been installed, and the general plan provides for the installation of four further units. The boiler plant is one of the largest that has yet been designed. Each boiler occupies a floor space of 29 × 31 feet and the height is 83 feet above the floor. The furnace measures 23 × 24 feet and the height is 55 feet above the ashpits, this exceptionally large space being provided with a view to burning blast-furnace gas mixed with pulverised coal. The gas is supplied through four horizontal burners on either side near the bottom, and for the powdered coal there are twelve feeders and four triplex burners. The gas distributing mains and the coal pulverising plants are described.

A. B. Helbig, *The Dangers of Pulverised Fuel* (Feuerungstechnik, June 1, 1922, pp. 188–190). The author gives reasons for his conviction that by the use of the necessary precautions coal-dust firing is attended with no greater risk than ordinary methods of stoking, and that the storage of large quantities of coal dust does not involve any special danger.

Use of Low-Grade Fuel.—*Utilisation of Pit Refuse for Raising Steam* (Iron and Coal Trades Review, July 28, 1922, vol. 105, pp. 120–121). The results of tests are given on the utilisation of low-grade fuel under boilers carried out at the Gordon House Colliery, Co. Durham. Three classes of fuel were used—cannel coal, belt pickings, and washery refuse. The latter proved to be nearly incombustible when fired by itself, but the difficulty was overcome by mixing it with a portion of cannel coal.

Fusibility of Coal Ash.—A. C. Fieldner, W. A. Selvig, and W. L. Parker, *Comparison of the Standard Gas Furnace and Micropyrometer Methods for determining the Fusibility of Coal Ash* (Journal of Industrial and Engineering Chemistry, August 1922, vol. 14, pp. 695–698). Coal ashes showing a softening temperature under 2600° F. by the gas furnace method can in the majority of cases be checked within 100° F. by the micropyrometer method, if fused in a reducing atmosphere of combustion gases similar to that employed in the gas furnace method. Some coal ashes will, however, show considerably greater differences between the two methods. Very refractory ashes, showing a softening temperature above 2800° F. as determined by the gas furnace method, tend to give considerably lower results by the micropyrometer method. The great majority of ashes from American coals, however, fuse below 2800° F. in the gas furnace. The two methods can therefore not be considered as strictly alternate methods for all ashes. In general, the micropyrometer method shows a point in the fusion process at which the particles become rounded and coalesce. This point agrees fairly well with the "down point" of the cones in the gas furnace method for ashes of low and medium fusibility (up to 2600° F.), since such ashes form a fairly fusible slag of short softening range. Refractory ashes form viscous slags with long softening intervals; therefore the down point of the cone may be from 100° to 500° F. higher than the fusing point as shown on the platinum strip. The micropyrometer method with reducing atmosphere has the advantage over the gas furnace in being much more rapid, and in dispensing with the special ashing of a quantity of coal.

Burning Bituminous Coal on Stokers (Mechanical Engineering, June 1922, vol. 44, pp. 373–374). At the joint Fuel Conference of a section of the American Society of Mechanical Engineers and local sections of other engineering societies three papers by G. E. Wood, O. J. Richmond, and R. A. Sanders dealt with the burning of bituminous coal on mechanical stokers. It is shown that as the ash, sulphur, and volatile contents of a soft coal increase, the operation of the stoker is hampered and the avoidable loss of combustible in the refuse increases. When working at 150 per cent. above rated capacity, it is most important that the coal should have a high fusing ash, that is, the ash should not melt under 2400° F., otherwise the operation of the stoker may be seriously interfered with.

Artificial Solid Fuel.—H. Danneel, *Metaldehyde as a Fuel* (Chemical and Metallurgical Engineering, August 2, 1922, vol. 27, pp. 216–218). A fuel approximating to the types of "solidified alcohol" used during the war, but employing synthetic acetaldehyde made from calcium carbide. It is being prepared in Switzerland for general domestic purposes. Its molecular weight corresponds with the formula $(CH_3COH)_4$, and the heat of combustion amounts to about 6000 calories per kilogramme.

II.—*COAL.*

Africa.—E. T. Mellor, *Recent Additions to the Knowledge of the South African Coal Fields* (Paper read before the Geological Society of South Africa: Colliery Guardian, July 28, August 4, 11, 1922, vol. 124, pp. 211–212, 272–273, 334–335). The paper deals more particularly with the Transvaal, and especially with the Witbank coal-field, where perhaps activity during recent years has been greatest, and where the largest additions to the known coal reserves have been made.

Algeria.—D. Dussert, *The Coal-Mine at Kenadsa* (Annales des Mines, 1922, vol. 1, Series 12, pp. 59–98). In 1917 a thin seam of coal was discovered in the southern Oran province of Algeria, at Kenadsa, and owing to the high cost of imported coal it was then and has since been worked. A description of the geology of the region is given. The indications are that further discoveries may be anticipated. The coal now mined outcrops and is to begin with 4 metres thick but soon pinches out to less than half a metre. Two short inclines have been driven 650 metres apart, in the direction of its western prolongation The overburthen is thin and sandy and easily removed. The ash varies considerably, from 3·37 to 12·4 per cent., and the sulphur ranges from 0·70 to 1·56 per cent. The fixed carbon is high, averaging about 73 per cent., with an average of about 21 per cent. of volatile matter. Coke made from the outcropping coal is somewhat brittle, but a very good grade can be made from coal obtained at greater depths. It is not possible to estimate the extent or capacity of the deposits as yet. The methods of working and the labour costs are given.

Australia.—D. Baker, *The Development of the Iron and Steel Industry in Australia* (Paper read before the American Iron and Steel Institute, May 26, 1922). The most important coal deposits so far developed in Australia are situated about the mouth of the Hunter River, Newcastle, New South Wales, and the upper seams of this deposit extend southward sixty miles under the city of Sydney at a depth of 2000 feet, and reappear again at the surface about forty-five miles south of Sydney, close to the coast. These two fields are estimated to contain 115,000 million tons of coal. All this coal is of coking quality. It is rather high in phosphorus, and that of the upper seams in the Northern field contains from 33 to 35 per cent. volatile matter. The lower seams of the Northern field are higher in volatile matter, up to 40 per cent., are very low in ash, and in many places the seams are 15 feet thick. In the Southern District the coal averages 18 per cent. in volatile matter, is low in sulphur, and the ash in the coke from the small coal will average about 16 per cent. The coke from the Northern coal is free burning, fairly hard but quite friable. The average weight per cubic foot is 25 lbs. The coke from the Southern District is very hard, dense, and slow burning, the average weight per cubic foot being 34 lbs. The large beds of lignite in Victoria are at present only worked to a very small extent. The only other State having large quantities of coal is Queensland, and the indications are that coal deposits there are very abundant.

Boring Operations for Lignite (South Australia Department of

Mines: Mining Review for the Half Year ended December 31, 1921, No. 35). An account is given of the boring operations conducted by the Department of Mines at Moorlands and Clinton. Numerous tables are given showing the analysis of samples of the lignite, together with a plan showing the location of each of the boreholes.

H. Herman, *Brown Coals of Victoria* (Geological Survey of Victoria, 1922, Bulletin 45). The distribution of the brown-coal seams of Victoria is described. During the last few years a considerable amount of research work has been carried out, and particulars are given of tests on the use of these coals for power production, including high and low temperature distillation, briquetting, its use under boilers, the use of pulverised brown coal, and gas-producer tests on the Morwell coal.

China.—*Coal in Northern China* (Colliery Guardian, June 16, 1922, vol. 123, pp. 1485–1486). Particulars are given relating to the coal-mining industry of Northern China. The coal is generally in the form of anthracite and bituminous coal. The four leading companies engaged in its recovery are the Société des Mines de Lincheng, the Kailan Mining Administration, the Shantung Mining Co., and the South Manchuria Railway Co.

Italy.—G. Pariente, *The Lignite Basin of Leonessa* (Rassegna Mineraria, 1921, vol. 55, pp. 68–69). The lignite in this district is brown and very moist. Analyses of samples from two localities show moisture 38·1 and 43·5 per cent.

G. Pariente, *The Lignite Basin in the Valley of Mercure* (Rassegna Mineraria, 1921, vol. 55, p. 69). The deposits of brown compact lignite are contaminated with clay and contain much moisture. Dried samples contain 20 to 44 per cent. ash, 33 to 48 per cent. volatile matter, 21 to 40 per cent. fixed carbon, and about 2 per cent. sulphur. The calorific value varies from 2859 to 4398.

Japan.—C. Iwasaki, *Fundamental Study of Japanese Coal* (Technical Reports of Tohoku Imperial University, 1921, vol. 2, pp. 235–275). The physical properties of the South Sakhalin coals have been investigated. Most of the coals are of low grade and both caking and non-caking coals are met with.

Philippine Islands.—*Iron and Coal in the Philippines* (Mineral Resources of the Philippine Islands, 1919–1920: Iron and Coal Trades Review, June 2, 1922, vol. 104, p. 818). This report, recently issued by the Division of Mines, Manila, contains information regarding the coal deposits in the Islands and the extent to which they have been worked. Estimates are also included as to the iron ore resources, with brief reports as to the work done in surveying and working them.

Spitzbergen.—Breuer and Zimmerland, *The Bituminous Coals of Spitzbergen* (Brennstoff-Chemie, 1922, vol. 3, pp. 98–103). The authors describe the situation, extent, and character of the various coal-seams in Spitzbergen.

World's Coal Resources.—*The Mineral Industry of the British Empire and Foreign Countries: Coal, Coke, and By-Products, Part III.* (Imperial Mineral Resources Bureau, London, 1922: H. M. Stationery Office). Part III. of the report deals with the coal resources of foreign Europe, Africa, America, and Asia. Statistics are given showing the production, imports, and exports of fuel during the period 1913–1919, and sketch maps are included showing the position of the principal iron ore deposits and coal-fields of the countries. The changes in the ownership of the coal resources of Europe as the result of the Peace Treaty are also shown.

Coal (Bulletin of the Imperial Institute, 1922, vol. 20, No. 1, pp. 114–121). Recent information concerning the chief coal deposits of the world is summarised.

Origin of Coal.—J. Roberts, *The Origin of Bituminous Coal and Anthracite* (Colliery Guardian, August 25, September 1, 8, 1922, vol. 124, pp. 459–460, 517–520, 593–594). The various theories of the origin and formation of bituminous coal and anthracite are discussed and the work of previous investigators reviewed.

P. F. Kendall, *The Physiography of the Coal Swamps* (Paper read before the British Association, September 1922: Iron and Coal Trades Review, September 15, 1922, vol. 105, p. 379).

Constituents of Coal.—F. S. Sinnatt and N. Simpkin, *The Inorganic Constituents of Coal with especial Reference to Lancashire Seams. Part II. The Iron in Coal* (Journal of Society of Chemical Industry, May 31, 1922, vol. 41, pp. 164–167 T). In the previous report it was suggested that the iron and manganese in association with coal might have some importance as agents in causing spontaneous heating during storage. The manner in which iron occurs in different coal varies over wide limits. Generally, the amount of iron that passes into solution when coal specimens are treated with water is small, but in isolated cases a very considerable proportion may pass into solution. The iron extracted by hydrochloric acid varies much more in quantity than that extracted by water. The iron present as pyrites represents the predominant variety. Silicate of iron is completely absent in certain coals, while in others it may amount to 10 per cent. of the total iron.

A. E. Findley and R. Wigginton, *Separation of the Constituents of Banded Bituminous Coal* (Fuel in Science and Practice, 1922, vol. 1, pp. 106–107). By the use of a combined method of sifting and classification according to density a sample of coal from the Kirkby Top Hards seam was separated into three main fractions, one with a density less than 1·3 containing 1·55 per cent. of ash, the second with density greater than 1·4 with an ash content of 30 per cent., and the third with a density greater than 1·4 containing 15·3 per cent. of ash. Fraction 1 appeared to be a mixture of clarain and vitrain, fraction 2 apparently consisted of durain, while fraction 3 appeared to be of cannel. The particles of fraction 1 exhibited attraction under the influence of an electric charge, while particles of fraction 2 showed mutual repulsion, and it was possible by magnetic means to bring about a partial separation of the two fractions from a mixture of a sample of the coal.

Sulphur in Coal (Brennstoff-Chemie, 1922, vol. 2, pp. 120–122). A review of the work of previous investigators on sulphur compounds in coal.

R. Ciusa and M. Croce, *Research on some of the Constituents of Lignite* (Gazzetta Chimica Italiana, February 1922, vol. 52, pp. 125–128). The lignites in question are from the deposits near Terni. The constituents are fichtelite, dinite (which again contains simonellite and könleinite), scheererite, and a complicated fourth group containing substances with higher fusion points, such as branchite, bombiccite, hartite, a special hydrocarbon peculiar to the lignites from Terni, and hoffmannite. The present series of investigations applied to the constituents of this fourth group. Formulæ and fusion constants are given for each of these constituents.

III.—*COKE.*

Properties of Coke.—H. D. Greenwood and J. W. Cobb, *The Structure of Coke* (Journal of Society of Chemical Industry, June 15, 1922, vol. 41, pp. 181–183 T). It is known that coking coals undergo a partial liquefaction at about 450° C., and the plasticity may be attributed to the melting of certain constituents of coal and their impregnation of the mass. The gases evolved by the decomposition of these and other constituents cause the formation of pores or cells in a mass, which gradually stiffens to rigidity as the decomposition proceeds. The cell structure retains its fundamental character, but is modified by the further evolution of gas as the temperature rises. The authors attempt to trace the changes from the newly formed cell structure to the final formation of high-temperature coke. Cokes were prepared from the same coal at three different temperatures, 550°, 850°, and 1100° C. The formation of high-temperature coke may be divided into three stages: (1) The first stage up to 550° C. is constituted by the initial cell formation, these cells having relatively thick walls of soft material of low specific gravity, the process being accompanied by a swelling of the charge; (2) between 550° and 850°

the mass as a whole shrinks, and an increase in specific gravity of the whole coke material ensues, the resulting coke having thinner but stronger walls, and the porosity reaching a maximum; (3) in the last stage the predominant factor is a further large contraction of the mass as a whole, the coke material undergoing no appreciable increase in specific gravity. The coke is strong, constituted of small pores with relatively thick walls. At no stage in coking to 1100° does the material approximate to the specific gravity of graphite, 2·3.

E. R. Sutcliffe and E. C. Evans, *The Influence of Structure on the Combustibility and other Properties of Solid Fuels* (Journal of Society of Chemical Industry, June 30, 1922, vol. 41, pp. 196–206 T). By careful attention to the structure of a fuel it is possible to produce at high or low temperatures of carbonisation a fuel of high degree of combustibility, high degree of hardness, and high apparent specific gravity. It has a pronounced cell structure with continuity in the distribution of cells, a large proportion of minute cells and porosity of cell walls. It is argued that with a highly combustible coke in the blast-furnace, the fuel consumption per ton of pig iron produced could be substantially lowered, and that ultimately it may be possible to smelt Cleveland ore with as low a consumption as 12 cwt. per ton of pig iron.

W. Boulin, *Metallurgical Coke* (Chimie et Industrie, January 1922, vol. 7, pp. 23–25). A brief description of the principal characteristics of good metallurgical coke, such as its crushing strength, brittleness, and porosity. It is pointed out that the conclusions as to the first-named properties, which are generally tested for in the cold, do not necessarily hold good when the coke is actually heated in the conditions it is used in.

A. Schmolke, *Volumetric Determination of the Real and Apparent Specific Weight of Coke* (Stahl und Eisen, August 10, 1922, vol. 42, pp. 1237–1240). A method has been devised for the determination of the specific weight of coke, using dried weighed lumps of coke without any further preparation. A gas under low pressure is used for estimating the porous space within the coke, and the operation takes much less time than using a penetrating liquid agent. Tests can be repeated on a single specimen as often as desired.

Coking Practice.—J. F. O'Malley, *Heating Coke-Ovens with Blue Water Gas* (Chemical and Metallurgical Engineering, July 12, 1922, vol. 27, pp. 75–78). In by-product coke-oven practice, when a continuous supply of gases is required for extraneous purposes and it is necessary to conform to required standards, it is difficult to secure such supply by a process of heating the ovens with lean gas and selling the rich gas. Coal shortage may necessitate the richer gas being drawn upon for oven heating, and in the result supplies of rich gas suffer. The use of a blue gas plant meets the necessities of such a case and possesses the advantage of constituting an entirely separate plant for the provision, independently of the gas required for heating the ovens themselves, making the whole output of coke-oven gas available for marketing, by-product recovery, and other purposes. Such a plant has been laid down in connection with the Semet-Solvay coke-ovens of the Empire Gas and Electric Company at Geneva, New York, where the gases are supplied to the neighbourhood and the coke made has to be of first-class metallurgical quality. The process of making blue gas consists in heating a bed of coal or coke to a sufficient incandescence by means of an air-blast, and subsequently passing steam through the heated fuel. The operation is cyclical, the steam being blown in both directions alternately, until the heat of the fuel has been lowered, whereupon the steam is turned off, and the air-blast used to increase the temperature of the bed again. The practice is described in detail, and the following comparative analyses of blue gas and of lean oven-gas are given :

	Blue Gas. Per Cent.	Lean Oven-Gas. Per Cent.
Carbon monoxide . . .	43·5	1·5
Hydrogen . . .	47·3	51·9
Methane . . .	0·7	26·5
Carbon dioxide . .	3·5	1·0
Oxygen . . .	0·6	0·3
Nitrogen . . .	4·4	17·4
Illuminants . . .	...	1·4

The calorific value of the blue gas is 302 B.Th.U. per cubic foot and its flame temperature 3470° F. The lean coke-oven gas has a calorific value of 380 to 450 B.Th.U. and a flame temperature of 4000° F., but varies within wide limits in both respects, and also as regards composition.

E. R. Sutcliffe and E. C. Evans, *Recent Developments in the Technology of Fuels* (Proceedings of the South Wales Institute of Engineers, July 1922, vol. 38, pp. 341–380). In the case of the iron and steel industry, despite the developments that have taken place during the past few years, there are still considerable possibilities of reducing the fuel consumption per ton of finished product. The Coal Conservation Committee of the Ministry of Reconstruction estimated that by grouping the blast-furnaces, gas-producers, coke-ovens, steel furnaces, &c., around a common centre, it would be possible to reduce the fuel consumption per ton of steel from 45 cwt. per ton to 35 cwt. The authors are of the opinion that by altering to some extent accepted methods of producing blast-furnace coke, it would be possible to effect a saving amounting in some cases to as much as 10 cwt. of coke per ton of pig iron produced. The authors discuss the possibilities of producing smokeless fuel economically on a commercial scale. In the process finally adopted by the authors they decided to carbonise the coal at temperatures which ran up to the highest possible point known in practice, and to leave in the resulting fuel as little volatile matter as possible. The process is based upon previous experimental work which has shown that by briquetting mixtures of (1) caking and non-caking coals, (2) raw and preheated resinous coals, or (3) resinous coal and coke breeze, under suitable conditions and without a binder, briquettes could be obtained which retained their shape when carbonised at either high or low temperatures. The coke briquettes burn very similarly to foundry coke, and a high-grade smokeless fuel can now be made in either gasworks, coke-oven plants, and other carbonising systems. The possibilities in connection with this material have yet to be tested on a large scale in blast-furnace practice, but theoretical considerations point to the view that the adoption of this coke for blast-furnaces would enable considerable economies to be effected. The economics of the process are discussed and particulars are given of costs of operation.

A. D. Young, *The Manufacture of Coke for Industrial Purposes* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 8, 1922, vol. 25, pp. 421–423). A general outline is given of the properties and manufacture of metallurgical coke.

C. E. Wallin, *The Operation of Koppers By-Product Coke-Oven Plant* (Journal of the Society of Chemical Industry, September 15, 1922, vol. 41, pp. 298–300 T). The Koppers coke-oven plant of the Dominion Iron and Steel Company at Sydney, Nova Scotia, consists of two batteries of sixty ovens each in operation, and a third battery of the triangular flue type has just been constructed but is not yet in operation. The capacity of the ovens is 11·3 short tons of dry coal. With a flue temperature of 2500° F. the charge is coked in eighteen hours. The batteries are constructed of silica brick and they have been worked for three and a half years with coal containing 11 per cent. moisture without suffering any undue deterioration. In coking washed coal in silica ovens no harm appears to be done to the brickwork if the coal is in a sufficiently fine state to prevent the drainage of the water. This state of division depends upon the nature of the coal and the percentage of water present. Practice in the recovery of the usual by-products is described.

F. W. Sperr, *By-Product Coking* (Journal of Industrial and Engineering Chemistry, September 1922, vol. 14, pp. 844–846). A review of recent investigations on the coking properties of coal, the coking process and by-product recovery, and the properties and utilisation of coke.

G. Weyman, *Increasing the Rate of Carbonisation of Coal* (Paper read before Institution of Gas Engineers: Gas Journal, 1922, vol. 158, pp. 864–868). An investigation has been made of the relation between the properties of various coals and the rate of carbonisation. The experiments show that if the rate of carbonisation can be increased by an alteration of the chemical and physical conditions, the calorific value of the gas is improved, and the thermal and volume yield per ton of coal is increased. The rate of carbonisation can be very considerably accelerated by the selection of suitable coals. When the rate is increased by increasing the carbonising temperature for a certain time, the calorific value of the gas obtained at the higher temperature is less than that of the gas obtained at the lower temperature, but volume for volume there is a slight balance in favour of the gas obtained at the higher temperature.

B. Barelle, *Contribution to the Study of the Coking of Sarre Coal* (Echo des Mines et de la Métallurgie, July 10, 1921; Revue Universelle des Mines, March 15, 1922, vol. 12, Series 6, pp. 540–541). To secure good coke from coal from the Sarre coal-field, the powdered coal should be charged in ovens heated to not above 320° C. for a period that has to be ascertained experimentally, and the ovens subsequently raised at a uniform rate, which has again to be ascertained beforehand, to a temperature of 750° C., and kept at this temperature until the coal has been thoroughly coked. Such a coke is strong, and the yield is far higher than that obtained under current conditions of practice.

H. V. Patterson, *The Coking of Illinois Coals in Roberts Ovens* (Blast-Furnace and Steel Plant, July 1922, vol. 10, pp. 388–393). A description of the practice which has been developed for the purpose of utilising the large deposits of feebly coking coals in Illinois and Indiana.

C. Berthelot, *Modern Processes for the Treatment of Lignite and its Derivatives* (Chimie et Industrie, June 1922, vol. 7, pp. 1079–1089). In Saxony, lignites are coked in an oven of the Zeigler type, which is illustrated. The Fischer oven is also used. Lignites from the Rhône valley have been treated in such ovens, the coke yield being 685 kilogrammes per metric ton, with 70 kilogrammes of valuable crude oils and 127 cubic metres of gas with a calorific value of 4000 calories. A review of the various processes employed is given, and the relative advantages of low and high temperature carbonisation discussed. The semi-coke obtained on distilling lignites still contains from 12 to 20 per cent. of volatile matter and is an excellent material for pulverised fuel, and also makes when mixed with pitch very good briquettes. During the war, lignites were largely used in Germany in gas-producers, and at present this practice is being continued in by-product recovery producers of the Mond type. A "trigaz" producer is also used, the material being coked by its own heat in a rotary hearth. A Delwik-Fleischer producer thus modified is described. Experiences in countries where such modes of utilising lignites have met with considerable success, render it likely that the French lignites could be very profitably treated by similar methods and a very useful and lucrative briquetting industry built up.

F. Lierg, *Chemistry of the Coking Processes* (Zeitschrift für angewandte Chemie, 1922, vol. 35, pp. 264–268). The author deals with the production of bituminous substances at high melting point, prepared by means of pyridine, and their application to the production of metallurgical coke from non-caking coal.

K. Sieben, *Is the Carbonisation of Coking Coals Endothermic?*

(Brennstoff-Chemie, 1922, vol. 3, pp. 209–211). The author reviews the work of various investigators showing that widely differing results have been obtained as to the heat requirements in the coking process. Calculations are given showing that the theoretical heat losses total altogether 630 calories per kilogramme. These results, however, could not be reproduced in practice, but in spite of this coke-oven builders will give a guarantee of about 600 calories per kilogramme for the heat losses on their ovens. If the reactions involved in coking were endothermic this would not be possible, but an exothermic reaction would assist in partially balancing such losses.

F. Foerster and W. Geisler, *Behaviour of Sulphur in Coal under Dry Distillation* (Zeitschrift für angewandte Chemie, 1922, vol. 35, pp. 193–198).

P. Schläpfer, *The Dry Cooling of Coke* (Stahl und Eisen, August 17, 1922, vol. 42, pp. 1269–1275). In view of the necessity of practising every possible economy in the use of fuel, it is proposed that instead of cooling coke by quenching with water, a system of dry cooling should be adopted. The actual heat loss in cooling coke from about 1000° C. to about 260° amounts roughly to 280,000 calories per ton of coke quenched, which would be sufficient to evaporate approximately 900 lbs. of water. The firm of Sulzer Bros., of Zurich, has constructed a plant at the gasworks at Schlieren, near Zurich, for the cooling of red-hot coke by blowing through it inert gases which afterwards are passed through boiler tubes. The plant has been two and a half years in operation, and on an average 23·6 tons of coke are cooled daily and 9·4 tons of water at 50° are converted into steam at 90 lbs. pressure. An installation is now under construction for two batteries, each of seventy coke-ovens, making blast-furnace coke.

Coke-Ovens.—*The Maritime Coke Works* (Colliery Guardian, July 14, 1922, vol. 124, pp. 79–82). Illustrated particulars of the new coke-oven and by-product plant of the Great Western Colliery Co., Ltd. Otto regenerative ovens have been installed and consist at present of a battery of thirty-two 10-ton ovens.

H. Prudhomme, *The Piette Coke-Oven* (Chemical and Metallurgical Engineering, April 26, 1922, vol. 26, pp. 794–796). The most important characteristics of the Piette oven are summarised and the results of operating tests are given.

A. Rühl, *Relation between Width of Coke-Oven and Coking Time* (Glückauf, September 9, 1922, vol. 58, pp. 1090–1092). The effect of the width of the chamber on the coking time is discussed. It is shown that, contrary to the opinion usually held, a larger quantity of coal per twenty-four hours can be coked in a narrow chamber than in a wider one. The tests made with ovens 20 inches wide, with a charge of 10·2 tons of coal, gave a coking time of twenty-eight hours, the amount of coal passed through being at the rate of 8·6 tons per twenty-four hours. In ovens 13½ inches wide the coking time was

15·3 hours with a charge of 7 tons, being at the rate of 10·5 tons of coal per twenty-four hours. The results are much the same both for ovens of silica brick and for those of fire-brick.

Hoyle Centrifugal Dryer at Tinsley Park Coke-Ovens (Colliery Guardian, June 30, 1922, vol. 123, p. 1603). An illustrated description is given of the Hoyle centrifugal dryer installed at the Tinsley Park Colliery near Sheffield, for reducing the moisture of the washed coal fed to the coke-ovens. The washed coal from the drainage hopper contains up to 20 per cent. moisture, and this is reduced by the dryer down to 8 to 9 per cent. in normal operation.

Low Temperature Carbonisation of Coal.—*Low Temperature Carbonisation* (Report of the Fuel Research Board for the Years 1921–1922, London, 1922, H.M. Stationery Office). The experimental and technical developments of low-temperature carbonisation during the past few years, not only at the Fuel Research Board at Greenwich but in other fields of activity, are discussed in detail.

Low-Temperature Carbonisation of South African Coal (Iron and Coal Trades Review, June 9, 1922, vol. 104, pp. 853). The results are given of a number of carbonisation experiments carried out by the Fuel Research Board with samples of South African coals. All the samples with one exception, on carbonisation at 600° C., yield a fairly coherent coke, which is an admirable smokeless fuel for domestic and other purposes.

Fuel Economy Committee of the British Association, Fifth Report (Iron and Coal Trades Review, September 15, 1922, vol. 105, pp. 380–381). A general review of the coal situation is given, and attention is drawn to the effects of the coal crisis on the iron and steel industry. With regard to the future home supplies of motor spirit and fuel oils, it would appear that the only practical way in which these can be extended is by the low-temperature carbonisation of coal. It seems now to be established, as the result of fairly large scale trials, that the average yields of the various products now obtainable by carbonising suitable British bituminous coals at 600° C. will amount (on the weight of the dry coal carbonised) to about 7·5 per cent. of tars and about 2·5 gallons per ton of motor spirit, besides about 3500 cubic feet per ton of about 800 B.Th.U. and a 70 to 80 per cent. residue of smokeless semi-coke.

J. J. Morgan and R. P. Soule, *Studies in the Carbonisation of Coal; Characteristics of Low-Temperature Coal Tar* (Chemical and Metallurgical Engineering, May 17, 24, 31, 1922, vol. 26, pp. 923–928, 977–981, 1025–1030). The authors have studied the tars obtained in the low-temperature carbonisation of coal, and the analytical results obtained are compared with those of coke-oven and gasworks tars. The density and free carbon content of the crude dry tars and the density, free carbon, and air melting point of the pitches remaining after fractional distillation under similar conditions have been determined. The values for the low-temperature tar have been shown to be notably lower than the corresponding figures obtained for the coke-oven and gasworks tars. The fractionation curves of the three tars, however, are very similar.

M. Laffargue and R. Jaugey, *Experiments on Low-Temperature Distillation : Utilisation of Lignites* (Annales des Mines, 1922, vol. 1, Series 12, pp. 327–347). An account of experiments carried out during the war in a Damour-Copaux oven heated electrically, in which samples of lignite were distilled at various temperatures, mostly at 500°, 660°, and 760°. Analyses of the crude lignites are given, and tables showing the amount and nature of the distillation products obtained.

By-Product Recovery.—F. M. Washburn and G. E. Muns, *Distribution of Tar Recovery from By-Product Coke-Oven Gas* (Chemical and Metallurgical Engineering, July 19, 1922, vol. 27, pp. 119–120). An investigation of the composition and quantity of tar removed from various points along the path traversed by the gas from two batteries of Wilputte ovens, each consisting of forty-four ovens. The coal mixture was 95 per cent. high volatile coal mixed with 5 per cent. low volatile coal. The oil and pitch residue percentages in the tar varied considerably at varying distances from the actual coke-ovens.

E. V. Espenhahn, *Recovery and Utilisation of Cyanide from By-Product Coke-Ovens* (Chemical and Metallurgical Engineering, May 17, 1922, vol. 26, pp. 938–941). A description is given of the Espenhahn process for the direct recovery of hydrocyanic acid and sodium cyanide from coke-oven gas.

H. D. Greenwood and H. J. Hodsman, *Factors influencing the Ammonia Yield in the Carbonisation of Coal* (Journal of Society of Chemical Industry, August 15, 1922, vol. 41, pp. 273–279 T.) The paper forms Part I. of an investigation on the factors which influence the ammonia yield during carbonisation of coal. The ammonia obtained in normal carbonisation practice represents only 15 to 20 per cent. of the nitrogen of the coal. A similar proportion is obtained as fresh nitrogen in the gas, and it is important in considering the development of by-product processes to note how much of this results from destruction of previously formed ammonia. The destruction of ammonia at low pressures and in atmospheres of air, of nitrogen containing 1 to 2 per cent. of oxygen, and of coal gases containing oxygen at temperatures up to 800° C. has been examined. The oxidation of ammonia in air and in contact with the fire-clay brick is distinctly retarded by water vapour present even in small proportions. In coal gas containing oxygen the destruction of ammonia is much less marked at corresponding temperatures than in air, and this destruction, owing to the preference of the oxygen for uniting with the hydrogen present in the coal gas, is due not to oxidation but to a process of dissociation. It is doubtful whether direct oxidation of ammonia occurs to an appreciable extent during carbonisation even when oxygen is present. The experimental work on this subject is being continued.

Gerdes, *Recovery of Primary Tar from Products of Steam-Boiler Firing* (Zeitschrift des Vereines Deutscher Ingenieure, September 16, 1922, vol. 66, pp. 869–873). A steam-boiler installation with means for recovery of primary tar is illustrated and described.

C. D. Carpenter and J. Barbor, *Concentrating Dilute Nitric Acid Solutions* (Chemical and Metallurgical Engineering, July 19, 1922, vol. 27, pp. 121–124). Deals with the problem of preconcentration and gives tables of concentrating rates, and analytical methods of fractionation. When the rate at which the distillate is removed in concentrating a boiling acid solution is known it is a simple matter to calculate the amount of distillate necessary to be removed by successive distillations in order to recover any desired amount of the acid at a higher concentration.

F. C. Zeisberg, *Thermal Considerations in Sulphuric Acid Concentration* (Chemical and Metallurgical Engineering, July 5, 1922, vol. 27, pp. 22–26). A study of the physical properties of sulphuric acid with formulas and diagrams for the determination of the heat required in concentration, and for ascertaining the thermal efficiency of the plant and methods employed.

IV.—*LIQUID FUEL.*

Esthonia.—E. H. Cunningham Craig, *Kukkersite: The Oil Shale of Esthonia* (Journal of Institution of Petroleum Technologists, July 1922, vol. 8, pp. 349–359). The name Kukkersite applied to the oil shale of Esthonia is derived from Kukkers, one of the localities where the deposit was first exploited. The beds of oil shale occur in the Cambrian and Silurian formations in the northern part of the Esthonian Republic, and the shale is not only the richest oil shale known, but it has been longest worked of any oil shale in the world. The volatile percentage of the shale has been given as between 52·5 and 65 per cent., while the fixed carbon is stated to be 5 to 11 per cent. Retorting tests show that while theoretically a yield of 90 gallons per ton of shale is possible, this quantity has been attained only occasionally in small scale tests. A yield in works practice of between 70 and 80 gallons per ton, and of crude oil not higher than 0·93 specific gravity, can be counted on using suitable retorts and methods of distillation. The quantity of shale at present in sight is estimated at 1000 million tons, but further excavations may prove a much larger quantity.

Galicia.—A. Millar, *Galicia and its Petroleum Industry* (Journal of Institution of Petroleum Technologists, July 1922, vol. 8, pp. 312–

340). After giving an historical account of the petroleum industry of Galicia, the author discusses the geological conditions of the district, the method of winning the oil, statistics of production, the yield of natural gas, the extraction of gasoline, conditions of storage, and the production of ozokerite.

Japan.—J. M. Clements, *Petroleum Resources of Japan* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, No. 1176–P, 8 pp.). Petroleum has been known to occur in parts of Japan for centuries, and a picture dating back to A.D. 668 shows an oil burning in Echigo province, which to this day is the principal source of petroleum in Japan. Oil deposits are found not only in Echigo and Shinano, but in Akita, Tolomi, Hokkaido, and Taiwan. These deposits are in all instances in Tertiary formations, and there are three well-defined horizons, the two lower being the most productive. No detailed estimate of the Japanese oil reserves have been made by the Japanese themselves, but foreign geologists have taken 90,000,000 barrels as a fair figure for the available reserves in proved ground.

Mesopotamia.—E. H. Pascoe, *Geological Notes on Mesopotamia with Special Reference to Occurrences of Petroleum* (Memoirs of the Geological Survey of India, 1922, vol. 48, 90 pp. with maps). The report describes generally the geological features of Mesopotamia, and deals with the prospects of the development of oil-bearing formations.

United States.—H. M. Payne, *Oil Industry of California* (Engineering and Mining Journal-Press, June 24, 1922, vol. 113, pp. 1099–1103). The author discusses conditions in the oil-fields of California.

C. Palmer, *Phosphorus in Californian Petroleum* (Chemical News, July 28, 1922, vol. 125, pp. 41–43). Californian heavy oils containing nitrogen bases have been found also to contain phosphorus. These nitrogen compounds and phosphorus compounds may be oxidised by minerals through the agency of underground water solutions and without the help of atmospheric oxygen. The association of phosphorus compounds with nitrogen compounds in oils of different fields is another link in the chain of evidence that Californian petroleum is of animal origin.

World's Resources of Petroleum.—D. White, *The Oil Supply of the World* (Mechanical Engineering, September 1922, vol. 44, pp. 567–569). An estimate of all the oil resources of all the regions of the world known to contain commercial deposits places the total oil reserves at 43,055 millions of barrels. The author summarises the measures necessary to be taken in order to increase and conserve the supplies of the United States.

Petroleum (Bulletin of the Imperial Institute, 1922, vol. 20, No. 2, pp. 253–265). A summary is given of recent information relating to the world's resources of petroleum.

The geology, occurrence, and working of petroleum deposits in Central and Southern American States have been made the subject of a number of communications before the American Institute of Mining and Metallurgical Engineers. These include the following:

V. R. Garfias, *Present Conditions in Mexican Oil Fields and an Outlook into the Future* (Transactions, 1922, No. 1153–P, 16 pp.); A. R. Redfield, *Petroleum Reserves of Central America* (*ibid.*, No. 1178–P, 10 pp.); L. G. Huntley and S. Mason, *Colombian Oil Fields* (*ibid.*, No. 1189–P, 9 pp.); C. B. Washburne and K. D. White, *Oil Possibilities of Colombia* (*ibid.*, No. 1168–P, 9 pp.); R. Arnold, B. Bryan, and G. A. MacReady, *Petroleum Resources of Venezuela* (*ibid.*, No. 1170–P, 5 pp.); and V. T. Marsters, *Oil Resources of Ecuador* (*ibid.*, No. 1174–P, 6 pp.).

Oil Shale.—D. E. Winchester (*Factors influencing the Value of Oil Shale Lands* (Engineering and Mining Journal-Press, July 8, 1922, vol. 114, pp. 61–66). Many considerations other than the unit content of the recoverable oil affect the value of an oil shale deposit. Comparatively little has yet been done toward the solution of the many problems connected with the mining of the shale and the recovery of its constituents. The author discusses the subject with regard to American deposits.

C. W. Botkin, *Relation of Shale Oil Residue to other Bitumens* (Chemical and Metallurgical Engineering, March 8, 1922, vol. 26, pp. 445–448). A preliminary study has been made of the resemblance of some of the physical and chemical properties of heavy shale oil to those of gilsonite, asphalt, and rosin.

A. E. von Groeling, *Recent Processes for Treatment of Oil Shale* (Petroleum, 1922, vol. 18, pp. 487–493, 539–545). A description is given of the American digesting process for the extraction of oil from shale, and of the apparatus used in the process. Colorado shale treated by this process gives a yield of 87 American gallons of oil per ton of shale. The oils obtained by the first distillation after crushing are of 0·807 specific gravity, and after the final distillation they have a specific gravity of 0·798 with a content of 24 per cent. of unsaturated hydrocarbon.

Oil Shales (Bulletin of the Imperial Institute, 1922, vol. 20, No. 2, pp. 250–253). Recent information concerning the world's sources of oil shales has been summarised.

Mining Petroleum.—E. R. Lilley, *Diamond Drilling for Petroleum* (Engineering and Mining Journal, July 22, 1922, vol. 114, pp. 152–156). The use of diamond drills for prospecting for oil is discussed Wells are being drilled in various parts of the United States by this method, but whether it can be used economically for drilling in producing fields is a question yet to be solved.

Refining of Petroleum.—E. W. Dean, H. H. Hill, N. A. C. Smith, and W. A. Jacobs, *The Analytical Distillation of Petroleum and its Products* (United States Bureau of Mines, 1922, Bulletin 207). The apparatus and procedure adopted by the Bureau of Mines for the distillation analysis of petroleum are described.

L. A. Mekler, *Thermal Problems of Petroleum Refining* (Chemical and Metallurgical Engineering, April 26, 1922, vol. 26, pp. 774–778). The author discusses petroleum refining practice from the view point of the combustion engineer.

C. J. von Bibra, *The Sulphuric Acid Treatment of Petroleum Products* (Chemical and Metallurgical Engineering, July 12, 1922, vol. 27, pp. 66–72). An investigation of the chemistry of petroleum treatment by sulphuric acid and the action of acid on the hydrocarbons it contains, with notes on refining generally.

E. W. Dean and W. A. Jacobs, *Production of Gasoline by Cracking Heavier Oils* (U.S. Bureau of Mines, Technical Paper 258, 1922, 56 pp.).

Properties and Tests of Petroleum.—*Methods for Testing Petroleum Products* (United States Bureau of Mines, 1922, Technical Paper 298). A detailed description is given of the methods of routine testing and inspection of petroleum products adopted by the Interdepartmental Petroleum Specifications Committee of the Bureau of Mines.

W. R. Ormandy and E. C. Craven, *The Physical Properties of Motor Fuels* (Paper read before the Institution of Automobile Engineers, February 21, 1922). The paper deals with the heat of combustion freezing point, range of distillation, flash-point, corrosive properties, and viscosity of liquid fuels for motors.

Valuation of Petroleum Properties.—R. H. Johnson, *Appraisal of Oil and Gas Properties* (Proceedings of the Engineers' Society of Western Pennsylvania, March 1922, vol. 38, pp. 35–43). Methods of appraising oil and gas properties should be based on three variables, one of these being age. The method which recognises three variables consists of plotting the production of the wells of the group in the second year against the production of the same wells for the first year, the third year against the second year, the fourth against the third year, &c. From these curves the production for the second year of any intermediate-sized well can then be read from the first curve, and with this reading the production of the third year can be read from the second curve, and so on. The appraisal of natural gas properties is much more difficult than that of petroleum properties, and the probable error in spite of the best methods may be roughly twice that of petroleum. The chief difficulty is that, whereas with oil the yield is normally the maximum capacity, in natural gas this is almost never the case, but is only a fraction of the potential yield, depending upon the ratio between line pressure and well pressure.

P. Ruedemann, *Application of Appraisal Methods for Taxation and Commercial Purposes* (Proceedings of the Engineers' Society of Western Pennsylvania, March 1922, vol. 38, pp. 46–54). The practical uses of valuations for the purpose of fixing taxation and negotiating transfers are discussed.

Use of Liquid Fuel.—R. C. Helm, *Use of Liquid Fuel in Metallurgical Furnaces* (Paper read before American Iron and Steel Institute, October 27, 1922). The introduction of by-product coke-ovens has increased the available amount of coal tar to such an extent that there is a sufficient supply for use as liquid fuel in metallurgical furnaces. As the production of tar goes hand in hand with the production of gas, the natural development of both these fuels has resulted in the practice of using them in combination as fuel for the open-hearth furnace. Coal-tar can, however, be burned advantageously alone. Various designs of furnace using liquid fuel and devices for burning such fuel are shown.

V.—*ARTIFICIAL GAS.*

Gas-Producer Practice.—G. Husson, *Considerations as to the Production and Utilisation of Low-Grade Producer-Gas for Heating Open-Hearth Furnaces* (Revue de l'Industrie Minérale, July 15, 1922, pp. 373–406). Steelworks engineers are well aware that the ordinary analyses of gas from gas-producers, which neither take into account the condensable products nor the water vapour present are of very little use as indications of the heating value of the gas itself in ordinary open-hearth furnace practice. Indeed such analyses differ little whether the volatile matters in the fuel used are 20 per cent. or 30 per cent., while the actual practical effect of the gases from such fuels differs radically. The ultimate value of producer-gas is that which it displays under furnace conditions, that is to say, its value for open-hearth purposes can only be ascertained by estimating the heat evolved on burning such gas at about 1000° C. in air at 1000° C., and by condensing the products of its combustion at 1600° C. This gives the available heat, above 1600° C. The expression $p' = \frac{L'}{M}$ when L = this available heat, and M = the calorific value of the amount of coal burned to make 1 cubic metre of gas, gives the "furnace yield" of the gas. A consideration of the results of such a view shows the importance of supplying the furnace with a gas containing the necessary number of calories available at above 1600°, and of supplying them by means of a gas having a maximum combustion temperature, with a minimum volume at the combustion temperature. These principles are applied to the investigation of the conditions under which fuel is gasified in a producer, formulæ, tables, and diagrams being given. The manner of conducting gas-producer practice is discussed, including cold driving and over hot driving, when using high-grade and when using low-grade coal. When all is taken into consideration the ordinary observations and theory do not fully explain the incontestable superiority of coal rich in volatile matter over coal low in volatile matter, for producer-gas production. The causes of this admitted fact are to be referred to a number of reasons, which are summarised, but which are unfortunately empirical. What emerges is the large part played by sheer skill on the part of the operator, which neither theory nor empiricism explain.

Factors affecting the Efficiency of Gas-Producers working on Bituminous Coal (Fuel Economy Review, May 1922, vol. 2, pp. 8–15; Iron and Coal Trades Review, June 9, 1922, vol. 104, pp. 856–857). A summary is given of the results obtained during independent investigations into certain factors which affect the efficient operation of gas-producers, made under the direction of the Fuel Economy Committee of the Federation of British Industries. It has been found that coals from particular areas or seams are more or less suitable in gas-producers, and the following is a general classification:

Fuels generally suitable. Northumberland, Derbyshire, Nottinghamshire, Leicestershire, Shropshire.

Fuels suitable in certain districts or seams. Lanarkshire, Fifeshire, Staffordshire, Warwickshire, Lancashire, Yorkshire, Cheshire.

Fuels generally unsuitable. Ayrshire, Cumberland, Durham, North and South Wales.

The series of trials had as its objective a comparison of the relative advantages and limitations of a number of steam-jet blowers, and of positive blast from a mechanical blower, when used for the gasification of typical coals under industrial conditions. A Wilson gas-producer having a fuel bed 6 feet 6 inches in diameter and a nominal rated capacity of 5 cwts. of coal per hour, was used. Tests were carried out on coal from Shropshire and South Yorkshire. Assuming that the fuel gasified is of reasonable satisfactory character, the working of the producer and the quality of the gas generated are mainly determined by the rate of gasification and the blast saturation temperature, and are independent of the means used for blast generation. The blast saturation temperature is of the greatest importance, and thermometers should in all cases be fitted to each producer to give an indication of the proportion of the steam used. The tests show that blast saturated at 55° C. gives gas of high calorific value. When live steam must be used for saturating the blast, and when the blast pressure does not exceed, say 2-inch w.g., it is shown that a simple type of solid jet may give the required blast saturation temperature. It is not, however, suitable for injection against high back-pressure. When working against increased blast pressures, blowers of the annular or multi-jet type are more efficient.

Positive blast from a mechanical blower can obviously be used against increased pressures, and with suitable regulation the saturation temperature may be satisfactorily controlled. The trials indicate the necessity for maintaining a constant pressure on the steam main when steam-jet blowers are used. The variations in boiler pressure which usually occur may cause a marked fluctuation in the quantity of gas generated. A reducing valve should always be provided to maintain a constant pressure in the steam supply main at the producers.

The Influence of Frequency of Charging on the Variations in Quality of Gas from Producers (Fuel Economy Review, August 1922, vol. 2, pp. 35–37). Tests were carried out under normal working conditions with Morgan gas-producers using Yorkshire and Nottinghamshire fuels. Trials were carried out in which the fuel was charged as rapidly as possible at about half-hourly intervals, and also in which the fuel was charged much more uniformly. In each case gas samples were taken at about five-minute intervals, and records were kept of the blast saturation and gas outlet temperatures. The results indicate that a marked variation occurs in the quality of the gas when the producers are heavily charged at infrequent intervals. This fluctuation appears to result, mainly, from a cyclical variation in the methane content of the gas, which attains a maximum within a few minutes after charging. The variation, which is appreciable with a producer working under satisfactory conditions, is more marked in the case of a producer with a shallow fire and high outlet temperature. The variation may be minimised by charging the fuel in smaller quantities at more frequent intervals, when a reasonably uniform quality of gas may be obtained at an almost constant temperature. A continuous feed is therefore of proved advantage in assisting to maintain a uniform quality of gas. Wher the arrangements permit only of intermittent feeding it is important that only light charges of fuel should be permitted. Where several producers supply gas to one or more furnaces they should not be fed in rapid succession, but in rotation at suitable intervals.

A. Korevaar, *A Study of the Theory of Gas-Producers as applied to Blast-Furnace Practice* (Chimie et Industrie, July 1922, vol. 8, pp. 14–25). The chemical and heat reactions resulting from the combustion of fuel for the production of producer-gas are discussed and illustrated diagrammatically. The three determining factors upon which the nature of the reactions depend are: (1) those relating to the producer itself, such as its dimensions and the materials of which it is built; (2) those relating to the fuel, such as its porosity and size of particles, and (3) those relating to the air, such as the velocity and temperature of the air current, the degree of oxygen concentration, and the proportion of water vapour it contains. Each of these factors is considered in detail, and the conclusions are applied to the working of a blast-furnace which may be regarded as a huge gas-producer. Practice goes to show that, as in a gas-producer, fuel economy in a blast-furnace can be attained by preheating the blast. Every stage of producer practice can be, and often is, reproduced in blast-furnace practice, and the results derived from the former can, with great advantage, be applied to the latter. In both cases high air temperatures are more beneficial than high air pressures.

Producer-Gas for Furnace Work (Engineering, March 24, 1922, vol. 113, pp. 347–351). In order to improve the efficiency of the manufacture of producer-gas, and at the same time to permit of the recovery of the valuable by-products lost in ordinary gas-producers, H. Nielsen has devised a combination of an ordinary producer with a low-temperature carbonising retort in which partial distillation of the raw coal is effected by the sensible heat of the producer-gas. The hot gas from the producer passes down through the retort in which it comes into contact with the raw coal. It distils and carries off with it the lighter hydrocarbons and emerges cool and with a much higher calorific value than on entry. The ammonia, tar, and oil can be extracted by the ordinary methods, and the gas even then is more effective for heating and power purposes than if used direct from producer. Illustrations of the plant and results of working are given.

A. Pigeot and F. Blache, *Note on the Utilisation of Low-Grade Fuels at the Montrambert and Bérandière St. Etienne Collieries* (Paper read before the Scientific Congress, Liége, 1922, Mining Section, pp. 15–24; Revue Universelle des Mines, August 15, 1922, vol. 14, Series 6, pp. 249–258). The description of the methods employed in utilising a waste coal which represented a fair proportion of the yield of the pits and contained from 42 to 45 per cent. of ash and 18 to 20 per cent. of volatile matter. The problem was solved by a twofold process of handling this material, which by its nature was not susceptible to washing. It was first coked in by-product recovery ovens, the impure coke thus produced being employed in gas-producers. The clinker being exceedingly fusible this coal could not be fired direct. On the other hand this objectionable property did not affect the coking results. A hard coke resulted containing up to 50 per cent. of ash, and sometimes even 60 per cent. The by-product yield from the coking operation was satisfactory, amounting to 40 kilogrammes of tar, 7 kilogrammes of ammonium sulphate, and 9·5 litres of benzol per ton. The gas obtained from the producers in which the coke was gasified contained from 14 to 15 per cent. of carbon monoxide and the same amount of hydrogen. After washing it proved quite suitable for use in gas-engines.

A. Dessemond, *The Utilisation of Fuel in Slagging Gas-Producers blown with Hot Air* (Liége Scientific Congress, 1922, Mining Section, pp. 1–14; Revue Universelle des Mines, August 1, 1922, vol. 14, Series 6, pp. 201–214). Describes and illustrates a gas-producer using low-grade fuel, in which the clinker is melted and tapped out as a slag. Tables are given showing the composition and ash of the fuels used and of the slags. The latter can be used for the manufacture of excellent portland cement.

Sawdust as Fuel (Fuel Economy Review, February 1922, vol. 1, pp. 14–16). Illustrated particulars are given of the plant of J. Sadd & Sons. Gas produced from sawdust is used for the driving of internal combustion engines and electric generators. Very little difficulty is experienced with the gas-producers, and the gas is of excellent quality.

Use of Blast-Furnace Gas.—N. H. Gellert, *The Value of Clean Blast-Furnace Gas* (Mechanical Engineering, May 1922, vol. 44, pp. 305–310). The economies resulting from the use of clean gas in hot-blast stoves and boilers have already been fully demonstrated by A. N. Diehl (Yearbook of American Iron and Steel Institute, 1915, pp. 314–425). Tests made by him at Duquesne showed that by using clean gas the available heat was raised from 77·03 to 79·51 per cent. of the total heat in the gas, and the total saving per ton of pig iron was 0·16 dollar, without taking into account the increased life of stoves, boiler combustion chambers, and labour for cleaning boiler tubes. Consideration is given by the author to the question of dry cleaning versus wet cleaning of gas, and of the available heat and flame temperature of the gas treated by each method. His conclusions are summed up as follows: Dry-cleaned gas at 400° F., even if it contains 35 grains of moisture per cubic foot, has a greater available heat value than wet-cleaned gas at 70° F., and with 7·98 grains of moisture per cubic foot. This heat is 6·5 per cent. greater for dry-cleaned gas than for wet-cleaned gas. There is no difference in flame temperature between the two gases.

H. S. Watts, *Fuel Gases in Iron and Steel Plants* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, July 20, 1922, vol. 110, pp. 153–157). The characteristics of blast-furnace, coke-oven, and producer-gas, and their use in continuous heating furnaces, is discussed.

G. M. Hohl, *Reducing Furnace-Gas Hazards* (Paper read before the National Safety Council, Detroit, August 30, 1922: Iron Trade Review, September 21, 1922, vol. 71, pp. 787–790). The author discusses some of the risks arising from the demand for more gas in engines than is available, and describes the safeguards for the blast-furnaces, gas-cleaning plants, and power-houses necessary to insure a uniform supply of gas. In the normal operation of the gas-handling plant, only two hazards can arise: first, the demand for more gas than is available, resulting in suction in the mains, or secondly too high gas pressure causing the water seals to blow out. When there is suction in the gas mains air is drawn in from many points and explosive mixtures result. The problem of maintaining pressure in the mains is greatly simplified by the addition of a gas-holder to the system.

This also acts as a reservoir to supply gas when normally there would be a shortage. The system in use at the Bethlehem plant is described in detail.

Use of Coke-Oven Gas.—T. Nicholson, *Coke-Oven Gas for Town Use* (Paper read before Coke-Oven Managers' Association : Gas World, 1922, vol. 76, Coking Section, pp. 52–55). During certain periods of the day gas for street lighting is taken from a battery of Semet-Solvay waste heat ovens at Willington, without separating into rich and lean fractions. The gas is passed through a water-tube condenser, a Livesey washer, a Holmes scrubber, a Maxim carburettor, and four iron oxide purifiers in series. Enrichment of the gas for illuminating purposes is not necessary.

P. Mallet, *The Utilisation of Coke-Oven Gases and the Possibility of their Substitution for Illuminating Gas* (Chimie et Industrie, March 1922, vol. 7, pp. 438–440). Draws attention to the difference in practice between coke-oven plants and town gas supplies, and suggests the partial substitution of the former for the latter. To sell to small consumers on an alleged thermal basis is to subject them to the mercy of the gas supply undertaking, and the calorific fluctuations are so great that this is prejudicial unless, as in Belgium, the gas is sold on a minimum basis and therefore often better, rather than worse, than the quality on which the price is based.

Utilisation of Coke-Oven Gas by Large Gas-Engines (Iron and Coal Trades Review, September 30, 1922, vol. 105, pp. 464). Particulars are given of the power plant operation by large gas-engines and driven by coke-oven gas at the Zollverein Colliery, Germany. The gas-engines, three in number, have been in operation since 1914, and are twin tandem double-acting 4-cycle engines, each developing 4500 brake horse-power, with a cylinder diameter of 3 feet 9¼ inches, 4 feet 3 inch stroke, and 94 revolutions per minute.

Utilisation of Waste Heat.—Three papers on this subject have been contributed to the proceedings of the American Society of Mechanical Engineers by H. B. Smith, *The Application and Performance of Waste Heat Boilers*; A. T. Lewis, *Utilisation of Waste Heat in the Steel Industry*, and by J. Brobston, *Utilisation of Waste Heat from Rotary Cement Kilns* (Mechanical Engineering, August 1922, vol. 44, pp. 513–518). In the first paper statistics of Babcock and Wilcox waste heat boilers installed to date are given. The rated boiler horse-power of these boilers is given below :

Open-hearth furnaces	102,211	Glass tanks	1,716
Cement kilns	15,834	Copper refining	1,347
Beehive ovens	11,730	Nickel furnaces	922
Zinc furnaces	8,740	Lime and dolomite furnaces	848
Heating furnaces	4,243	Malleable iron furnaces	373
Oil stills	3,975	Silicate furnaces	232
Gas benches	1,328		

making in the aggregate 153,499 rated boiler horse-power. For this class of boiler three types are in use: (1) 18-high 3 pass boilers for such types of industrial furnaces as require comparatively high draught; (2) 24-high 3-pass for furnaces of medium draught, and (3) 27-high single-pass boilers for low draught furnaces. It is essential to keep all boilers of these types in good condition to ensure efficiency, but with care upkeep expenses are low. Figures are given showing the results obtained in such boilers when used with open-hearth furnaces.

In the second paper the point is made that a steel plant is not complete without waste heat utilisation. In a 70-ton open-hearth furnace from 70,000 to 100,000 lbs. of gas normally enters the stack per hour at a temperature of 1000° to 1200° F. In ordinary practice 18 per cent. of the heat developed is used for useful work, 3 per cent. is lost in the slag, 40 per cent. in the stack gases, and 39 per cent. is lost by radiation and in other ways. At least 350 horse-power per furnace can be developed in such a furnace by means of a waste heat boiler. Diagrams of installations and heat balances, both of open-hearth and of mill furnaces, are given.

In the third paper, interesting details are given of waste heat utilisation from rotary cement kilns used for burning portland cement.

Utilising Steam from Waste Heat Boilers (Foundry, September 1, 1922, vol. 71, pp. 719–720). An illustrated description is given of a row of steam-heated core-ovens at the plant of the Dayton Malleable Iron Co., Dayton, Ohio. This company has two of its melting furnaces fitted with waste heat boilers, and utilises the steam for heating the core-ovens.

Gas-Engines.—F. Johnstone Taylor, *British Blast-Furnace Gas-Engines* (Iron and Coal Trades Review, September 22, 1922, vol. 105, pp. 422–424). The author discusses the relation of design to reliability and efficiency, and describes the Vickers, Galloway, and Premier types of gas-engines. The double-acting tandem four-stroke engine is, so far as British practice is concerned, the most reliable and efficient of the blast-furnace gas-engines.

Combustion of Gases.—W. Payman and R. V. Wheeler, *Combustion of Gaseous Mixtures* (Chemical Society, Transactions, 1922, vol. 121, pp. 363–379). The law of speeds of propagation of flame in complex mixtures of different inflammable gases with air and oxygen are stated.

VI.—*COAL WASHING AND HANDLING.*

Coal Washing.—A. Thau, *Coal Cleaning, with Particular Reference to the Production of Coke with Low Ash* (Stahl und Eisen, July 27, August 10, 1922, vol. 42, pp. 1155–1158, 1242–1249). The flotation method is advocated as the most economical and efficient process for removing the ash from coal. Ordinarily it is possible to reduce the ash content by 70 per cent., and the coke is improved both chemically and physically. At the Gelsenkirchen works two experimental ovens have been built, with chambers of half a ton capacity each. Systematic tests are being made in these to determine the effect of varying the width of the chambers, the temperature, the mixtures, and composition of the charge. The quality of the coke can be considerably improved by the addition of coal sediment with low ash content. Both the chemical and physical properties of the coke undergo improvement, and such coke gives much better results in the blast-furnace.

Washery at Deep Navigation Colliery (Iron and Coal Trades Review, May 19, 1922, vol. 104, pp. 738–739). The general arrangement of the coal-washing plant at the Deep Navigation Colliery, South Wales, is described and illustrated. The plant has a capacity of 500 tons in eight hours.

O. C. Ralston and A. P. Wichmann, *The Froth Flotation of Coal* (Chemical and Metallurgical Engineering, March 15, 1922, vol. 26, pp. 500–503). The authors discuss the work of previous investigators on the application of the froth flotation process for the recovery of washery refuse and unconsumed coal in ashes.

O. C. Ralston and G. Yamada, *Froth Flotation Tests on Bituminous Coking Coal* (Chemical and Metallurgical Engineering, June 7, 1922, vol. 26, pp. 1081–1086). A study of the applicability of froth flotation to the treatment of fine sizes of bituminous coal from Wilkeson, Washington. Tests have shown that the cleanest coal can be floated first, the bony coal next, and the ash last, by ordinary froth flotation. Very thin oils or soluble frothing agents work best.

W. D. Green, *Recovering Coal and Coke from Ashes* (Chemical and Metallurgical Engineering, April 12, 1922, vol. 26, pp. 701). The author describes the treatment of ashes and cinders by flotation for the recovery of unburned coal. The material was treated in a Janney test machine.

Briquetting Coal.—H. P. Vowles, *The Briquetting of Black Coals and Lignite* (Fuel Economy Review, 1922, vol. 2, pp. 25–27). Since dry lignite dust is very inflammable, steam drying is exclusively used; with coal (especially anthracite) there is less danger, and hot air or hot flue-gases may also be used for drying purposes. Lignites may be briquetted without the addition of a binder; the press universally employed is of the extrusion type, a continuous strip of compacted material being produced, which is afterwards cut up as required. Black coal requires the addition of 7 to 9 per cent. of medium soft coal-tar pitch.

The New Leeds Briquette Works (Iron and Coal Trades Review, July 21, 1922, vol. 105, p. 75). A short description is given of the plant of these works belonging to Yeadon, Son & Co., for the manufacture of rectangular briquettes. The type of press used has an output capacity of 6 tons per hour, and produces four briquettes at one operation, showing a variation of no more than half an ounce in weight.

Storage and Spontaneous Combustion of Coal.—W. Dederichs, *Spontaneous Combustion of Coal* (Chemiker Zeitung, 1921, vol. 45, pp. 1181–1182). The causes of spontaneous combustion and the means of its prevention are discussed. The author is of the opinion that bacteria are the most important agents in starting fires in coal piles.

O. P. Hood, *Factors in the Spontaneous Combustion of Coal* (United States Bureau of Mines, 1922, Technical Paper 311). The paper outlines the more important factors in the spontaneous heating of coal.

H. H. Stoek and J. V. Freeman, *The Storage of Bituminous Coal* (Paper read before American Iron and Steel Institute, October 27, 1922). The effect of storage on the coking properties of coal is generally to decrease the coking properties of most coals, but they vary widely in this respect. Data as to the effect of weathering of coal on the coking capacity and on the yield of by-products have been collected and tabulated, and the points to be considered in the choice of a storage system are stated.

PRODUCTION OF IRON.

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I.—*MANUFACTURE OF PIG IRON.*

Blast-Furnace Plant and Equipment.—*The Park Gate Ironworks* (Iron and Coal Trades Review, September 8, 1922, vol. 105, pp. 338–340). An illustrated description is given of these works, which comprise up-to-date blast-furnaces, steel plant, and rolling-mills (see this Journal, p. 241).

The Devonshire Works of the Staveley Coal and Iron Company, Ltd. (Iron and Coal Trades Review, August 25, 1922, vol. 105, pp. 249–253). A detailed illustrated description is given of the lay-out and equipment of these works, which includes blast-furnaces, coke-ovens, plant for the manufacture of tar-macadam from blast-furnace slag, by-product plant, and chemical works (see this Journal, p. 237).

Rebuilt Emporium Blast-Furnace (Iron Trade Review, September 7, 1922, vol. 71, pp. 651–653). Illustrated particulars are given of the reconstruction of the blast-furnace plant of the Emporium Iron Co., Pennsylvania. The furnace has been fitted with a new top and mechanical filling equipment installed. New storage bins and a pig-casting machine have been added.

R. Peters, jun., *Eastern Blast-Furnace* (Iron Trade Review, May 4, 1922, vol. 70, pp. 1258–1260). An illustrated description is given of the new blast-furnace recently erected at the plant of the Thomas Iron Co., Easton, Pa.

E. C. Kreutzberg, *Ojibway Plant to Resemble Gary* (Iron Trade Review, August 17, 1922, vol. 71, pp. 439–443). Particulars are given of the development of the iron and steel plant at Ojibway, on the Detroit River, Canada. The plant, which is owned by the Canadian Steel Corporation, a subsidiary of the United States Steel Corporation, will have approximately the same tonnage capacity as the Gary works. Progress has been made in the construction of an unloading slip and docks for ore vessels and two blast-furnaces are in an advanced stage of construction.

Centrifugal Blast-Furnace Blowers (Iron and Coal Trades Review, June 16, 1922, vol. 104, pp. 896–897). The general design of the blast-furnace turbo-blower designed and built by the British Thomson-Houston Co., Ltd., Rugby, is given. The machine has a capacity of 40,000 cubic feet of free air per minute and a delivery pressure of 25 lbs. per square inch when running at 2740 revolutions per minute, the inlet air being desiccated before admission to the blower. The blower is driven by means of a high-pressure multi-stage Curtis turbine, the turbine being coupled to the blower shaft through a flexible coupling.

New Pig-Breaker (Iron and Coal Trades Review, June 30, 1922, vol. 104, p. 972). A new type of pig-breaker for use in foundries is described. An outstanding feature is that its power is derived from a small quantity of sporting powder, its combustion being so controlled that the maximum pressure of the gases is reached before the hammer moves to break the pig. The machine is portable, weighing only 2 cwt.

Blast-Furnace Practice.—A. K. Reese, *The Bases of Modern Blast-Furnace Practice.* (This Journal, p. 9.)

M. Derclaye, *The Influence of Superheating, of Drying the Blast, and of Enrichment, on the Working of Blast-Furnaces* (Liége Scientific Congress, 1922, Metallurgical Section, pp. 99–160 : Revue Universelle des Mines, October 1, 1922, vol. 15, Series 6, pp. 1–62). Discusses at length and in considerable detail the broad questions indicated, more particularly in regard to actual experience on the No. 4 blast-furnace at the Providence works of the Ougrée-Marihaye Company. Full details of the charges, blast temperatures and pressures, and thermal balance sheets are given. The economy derived from the use of hot blast is incontestable, but in practice it is found that there is a temperature limit to heating the blast beyond which it is no longer economic or advantageous. The economy resulting from heating the blast from 800° C. to 900° C. is much smaller than that derived from heating it from 300° to 400°. This applies, indeed, to every incremental increase of 100°. The economy at 300° to 400° was found to amount to 84 kilogrammes of coal per ton of pig iron, whereas, by heating the blast from 400° to 900° the saving was only 45 kilogrammes. The conclusion drawn is that there is no sufficient benefit to be derived from heating the blast beyond 800° to warrant the increased cost of doing so.

Turning to the question of the drying of the blast, Gayley's original figures relating to the Isabella furnace are reproduced and subjected to analysis ; while the experience obtained at blast-furnaces in Great Britain and on the Continent, where dry blast has been used, is also taken into detailed consideration. The question is asked whether the incontestable saving in fuel found at plants where dry air is used applies invariably and to all plants, such, for example, as French and Belgian blast-furnaces making pig iron from the minette ores of Briey. The actual costs of its application are dissected and the conclusion is arrived at that it cannot, in some circumstances, be made to pay. Further, the actual fuel economy attained is due far more to the use of blast of higher temperature than to drying the blast. It is shown that this rise in temperature accompanied the original Gayley experiments, and their result is to be ascribed largely to this cause rather than to desiccation. The question is answered in the negative, and the results in America are ascribed to conditions not invariably occurring elsewhere. Further, the conclusion is arrived at that if, at the Isabella furnace, the blast had been heated to 700° instead of being dried, exactly the same results would have been obtained in regard to fuel economy. Moisture-containing blast heated to 700°, and dry air blast at 363°, are declared to have identical influences in this respect. In regard to minette ores the heating of the blast to 700° obviates all disadvantages arising from the presence, originally, of moisture in the blast.

An account, finally, is given of the experiments carried out at the Providence furnaces on the enrichment of the blast by means of oxygen. The first result is increased temperature at the tuyeres. Moist blast contains more oxygen than dry blast, owing to the decomposition of the water vapour. In the experiments described, 5 per cent. additional oxygen was added to the undried hot blast. Tables are, however, given showing the calculated effect of varying percentages of oxygen additions. In practice, and at the Ougrée-Marihaye plant on a 100-ton blast-furnace, with oxygen enrichment in the ratio of 21 : 23, the fuel economy realised was 2·5 to 3 per cent. per ton of pig iron, and the yield was increased 12 per cent. These figures agree well with theory and with the calculations based on theory, which are given in full. It is regarded as proved, therefore, that oxygen enrichment yields economical results, but the advantages to be derived from such practice grow less and less in proportion as the oxygen percentage is increased. The theoretical gain is shown below :

Oxygen by Weight in Mixture. Per Cent.	Oxygen by Weight added per Kilogramme of Air. Grammes.	Coke Saved. Kilogrammes.	Proportion of Coke saved. Per Cent.
28·5	77·6	180	25·0
37·5	233·0	360	50·0
54·7	700·0	540	75·0
100·0	Pure oxygen	720	100·0

This table shows that to obtain a 25 per cent. saving only 77 grammes of oxygen need be added, that is to say, the percentage is brought up from 23 to 28·5 per cent. (an actual addition of 5 per cent.), whereas to save a second 25 per cent., 233 grammes of oxygen must be added per kilogramme of air, while, finally, the percentage necessary to economise from 75 per cent. to 100° per cent. (actually 32 per cent. of fuel) is 45 per cent. additional oxygen. The following practical conclusion is deduced from the experiments: The use of 5 per cent. by volume oxygen enrichment does not, taken as a whole, improve blast-furnace practice, inasmuch as what is gained in coke economy is lost in the thermal and motor values of the gases. Further increase in oxygen enrichment will accomplish no fresh result as the whole of the indirect reducing activities of the gases will be exhausted, the ratio $m = 1{\cdot}21$ tending to approximate with Gruner's ideal 1·57, at which all the oxygen in the burden is removed by the carbon monoxide. Five or six per cent. oxygen enrichment is therefore the upper limit feasible in practice, and something less is advisable if real benefit is to be obtained. While, within these limits, the hopes some investigators have entertained of dispensing with Cowper stoves altogether will not, in practice, be realised, the ultimate benefit to be expected will arise from the fact that the output of a furnace may be increased by about one-third.

A. G. Betts, *Cheap Oxygen* (Chemical Age, 1922, vol. 30, p. 21). According to the author the introduction of pure oxygen into the blast-furnace instead of air would result in higher temperatures, and practically the same advantages as smelting in electric furnaces. This applies particularly to the smelting of ferro alloys.

Preusler, *Transmission of Heat from Fluids and Gases in Relation to Rates of Speed* (Italia Eisere, June 16, 1921, p. 827). Disputes the views enunciated by Nusselt, and claims that the economy resulting from heating the blast does not arise from the higher rate of speed conferred on the gases, but on the additional heat supplied. The shortening in the period of heating is due only to the consumption of more gas. The economy due to increased blast pressures in Cowper stoves is due to the more complete combustion of the gases at the increased stove temperatures, and to the conversion of gas possessing low radiant heat qualities into gas with high heat radiance.

C. Schwarz, *Influence of the Velocity of the Gas and Blast on the Heat Transfer in the Checkers of Blast-Furnace Stoves* (Stahl und Eisen, September 7, 14, 21, October 5, 1922, vol. 42, pp. 1385–1392, 1424–1430, 1456–1460, 1519–1523).

H. von Jüptner, *Processes in Gas-Producers and Blast-Furnaces* (Zeitschrift für physikalische Chemie, 1922, vol. 100, pp. 231–237). By the correct reduction of iron oxide by carbon in the blast-furnace the amount of fuel used is reduced, but the reduction proceeds slowly. In the electric smelting furnace better results are obtained with wood charcoal as it is more porous than coke, and the more open condition of the charge accelerates the reduction.

S. L. Goodale, *The Control of Silicon in the Blast-Furnace* (Blast-Furnace and Steel Plant, May, July, 1922, vol. 10, pp. 274–278, 367–370). The critical temperature below which it seems not to be possible to reduce silicon by means of carbon is about 1450° C., and above this temperature the reaction can take place only so fast as a surplus of heat is supplied, which amounts to about 4302 calories per unit weight of oxygen or 4920 calories per unit weight of silicon involved. The surplus heat from about 5·4 units of weight of coke is required for the heat absorbed in the reduction of 1 unit of weight of silicon. This is probably approximately the amount of coke actually required in the furnace for this purpose. The other conditions which affect the reduction of silicon are the amount of slagging bases in comparison with the amount of silica and the amount of silicon in the iron. Silicon unites with some of the iron to form a compound FeSi which dissolves in the iron. The heat of this reaction and solution is probably not very great, but it assists slightly towards the reduction of silicon from silica. The heat of solution of silicon in iron decreases rapidly as the amount of silicon in the iron increases. This factor makes it increasingly difficult to secure an additional unit of silicon in the iron, in proportion as the amount of silicon already in the iron is greater. A basic slag tends to hold silica as such much more strongly than acid slag. One of the important means by which the temperature of the blast-furnace hearth is maintained at a high level is by getting the mixture of slag-forming materials such that the slag will not fuse down into a thin liquid except at a high temperature. The result of this is to hold the material in the stream of superheated gases for a longer time until it attains the higher temperature necessary for fusion, while the material is thus held at a high heat in the presence of carbon-monoxide, and in contact with coke the conditions are attained which are needed to reduce silicon.

A. Killing, *Difficulties in the Blast-Furnace due to Sulphur* (Stahl und Eisen, June 22, 1922, vol. 42, pp. 968–971). The working of a furnace running on foundry iron is described, the charge being made up of ore in the following proportions: 33 per cent. of minette ore, 25 per cent. of hæmatite, 15 per cent. of Swedish ore, 10 per cent. of briquettes, 7 per cent. of pyrites residues, and 10 per cent. of cinder. The pig iron contained 0·02 per cent. sulphur. Difficulty arose through the slag becoming too stiff to run off and the tuyeres choked and burnt out. Analysis of the slag showed that the sulphur had increased to 4 or 5 per cent., causing the slag to lose its fluidity. On altering the composition of the charge till the sulphur in the slag fell below 3 per cent., the difficulty was overcome.

H. R. Stuyvesant, *Alabama Furnace breaks Output Record* (Iron Age, May 25, 1922, vol. 109, pp. 1443–1445). Operating data are given of the No. 1 Gadsden furnace of the Alabama Co. During the first half of March 1922 the average daily production was 261 tons of foundry iron on 2795 lbs. of coke per ton of iron, while the average for the month shows 254 tons of iron on 2820 lbs. of coke.

R. T. Slee, *The Use of Explosives in Steelworks* (Proceedings of the Australasian Institute of Mining and Metallurgy, June 1921, No. 42, pp. 25–29). The author gives an account of the methods employed at the Newcastle Steel Works, New South Wales, in the use of explosives for removing the lining and salamander of a blast-furnace. Explosives were also used for splitting steel ingots longitudinally for examination of the interiors.

Blast-Furnace Gas Cleaning.—J. Raick, *The Electrostatic Precipitation of Fumes and Dust by the Cottrell Process* (Liége Scientific Congress, 1922, Metallurgical Section, pp. 81–96: Revue Universelle des Mines, September 15, 1922, vol. 14, Series 6, pp. 447–464). An illustrated description of the latest type of Cottrell precipitation plant in America, with notes as to the capital cost of such an installation, and its cost of working and maintenance. Reference is made to the system as applied elsewhere, notably at a sulphuric acid plant at St. Gobain (Aubervilliers). Its installation must be judged mainly from the point of view of whether the precipitated dust has a serious commercial value.

W. F. Clements, *Cleaning Blast-Furnace Gases* (Paper read before the Barrow and District Association of Engineers: Iron and Coal Trades Review, June 2, 1922, vol. 104, p. 825). The author presents some interesting figures relating to economies to be derived from the use of dry-cleaned blast-furnace gas, on the basis of 2,000,000 cubic feet per hour with two standard units of Halberg-Beth cleaning plant.

J. W. Gilles, *Pyrophoric Dust in Blast-Furnace Gases* (Stahl und Eisen, June 8, 1922, vol. 42, pp. 884–891). A careful investigation has been made at the Wissener ironworks to discover the cause, and to find means for the prevention of the ignition on exposure to air of the fine dust collected in the filter-bags of the plant for dry cleaning the blast-furnace gas. The temperature in the filter chambers, while the dust is collecting, is about 80° to 90° C., but the dust after being drawn off soon rises in temperature, and on turning over with shovels begins to glow and gives off fumes which have an unpleasant effect on those handling it. In changing a worn-out filter-bag, the whole chamber has been known to catch fire and burn out if left open too long, and the only remedy is to draw off the gases from the chambers before opening and change the bag in the quickest possible time. Analyses of the dust at the Wissener works show that it contains a high proportion of manganous oxide, which on spontaneous heating is burnt to manganese dioxide, and it is concluded that manganous oxide is the constituent which possesses the pyrophoric property. No means have yet been found to prevent the heating up of the dust in contact with air, but experiments are in progress with a view to oxidising the dust in the gases before entry into the cleaner.

Electric Smelting of Iron Ore.—R. C. Gosrow, *Notes on Iron Ore Smelting in California* (Chemical and Metallurgical Engineering, September 6, 1922, vol. 27, pp. 490–493). A description of the history of iron ore smelting in California, with an account of the ore resources, and of the present condition of the iron industry in the State. Both magnetic ore with 64·37 per cent. of iron and hæmatite with 44·67 per cent. of iron were known to be located near Clipper Gap, Placer County, as far back as 1854, but it was not until 1869 that attempts were made to create an industry, with the promise of a State bounty to aid it. The scheme fell through, however, and the first furnace actually built was not put into operation until 1880. It was erected at Hotaling and was of small size, with a capacity of 25 tons per day. Pine charcoal from local woods was used as fuel. The fuel consumption was a ton of charcoal per ton of pig iron produced. Foundry and forge grades were made. A rich find of magnetic iron ore at Pitt River, Shasta County, with 65 per cent. of iron, led eventually to the formation in 1907 of the Nobel Electric Steel Company, and a Heroult furnace was installed by its inventor at a new township which adopted his name. The power at Heroult was derived from waterfalls in the Sierra Nevada mountains. After a good many vicissitudes, and many modifications from the original design, the furnace was, in 1911 and 1912, making 20 tons of foundry iron per day, with a power consumption of 2700 kilowatts hour per ton of pig iron. Electric pig iron, despite the fact that it yielded castings of extreme fineness and softness, was unable commercially to compete with Southern and Mid-West blast-furnace pig. During the war the company abandoned pig iron manufacture in favour of making ferro alloys. Simultaneously with the electric operations at Heroult in 1907 many attempts were made elsewhere to utilise the fuel oils of California for blast-furnace reduction of local ores, but it was found that the ores did not reduce, and that ferrous oxide and iron silicate slags resulted. Attempts to make spongy iron by means of oil firing were also unsuccessful, and the rich ores of the State still await satisfactory commercial development.

G. Herlin, *Electric Smelting and Blast-Furnace Installations at Porjus* (*Sweden*) (Jernkontorets Annaler, 1922, vol. 77, pp. 99–132). A detailed description is given of the electric smelting furnaces, the buildings and equipment in connection therewith.

J. A. Leffler, *Electric Production of Pig Iron in Sweden* (Teknisk Tidskrift, 1921, vol. 51, pp. 59–71).

Electric Smelting of Pig Iron in Sweden (Engineer, July 7, 1922, vol. 134, pp. 5–6). A short review of the development of the electric smelting of iron ore in Sweden, the practice followed, and the economic aspect of the process.

Accidents in Iron Works.—L. W. Chaney, *Causes and Prevention of Accidents in the Iron and Steel Industry*, 1910–1919 (United States Bureau of Labour Statistics, June 1922, Bulletin 298). A study has been made of the causes and nature of accidents in the American iron and steel industry during the last ten years.

Iron Industries of Various Countries.—*Mineral Development in Mysore* (Mining Journal, July 1, 1922, vol. 138, p. 498). The plant of the Mysore Distillation and Iron Works at Bhadraviti on the Shimoga branch of the State Railway has now been completed. It comprises one blast-furnace capable of producing 60 tons of charcoal pig iron a day, together with an elaborate wood distillation plant in which 100,000 tons of wood are to be carbonised annually. The works are under the management of the Tata Iron and Steel Company, who are acting as agents for the Mysore Government. The ore is obtained locally, the existence of a large mass of hæmatite and magnetite having been proved in the Shimoga district, with iron running from 56 to 62 per cent. and phosphorus 0·05 to 0·09 per cent. It is expected that the product will be somewhat inferior to the best Swedish charcoal iron, but somewhat better in quality than the West Coast hæmatite.

The Wabana Ore Agreement (Iron and Steel of Canada, July, August, 1922, vol. 5, pp. 121, 144). The British Empire Steel Corporation has undertaken to construct a plant capable of producing 100,000 tons of pig iron annually in Newfoundland before 1928. This action will be taken following an agreement between the corporation and the Newfoundland Government, the former having arranged to pay a royalty of 25 cents per gross ton for every ton of ore that is mined in the colony. The corporation further undertakes to erect coke-ovens and to expend three million dollars in Newfoundland before 1926. Materials for the construction of the new plant are to come in duty free. Rights have been granted regarding tax exemption and water power. The royalty of 25 cents per gross ton of ore mined is to continue in force till December 1940.

Ore shipped to Nova Scotia shall pay an export tax of 25 cents per ton, and ore may be shipped free of tax to countries other than Canada, provided the company spend three million dollars on improvements of their plant during the next five years, and that they give notice before 1926 of their intention to erect a plant to smelt 100,000 tons of pig iron annually, otherwise a tax of 10 cents per ton will be levied on such ore.

D. Baker, *The Development of the Iron and Steel Industry in Australia* (Paper read before the American Iron and Steel Institute, May 26, 1922, 40 pp.). The first attempt to manufacture pig iron in New South Wales was in 1852 at the Fitzroy Ironworks, near Mittagong, on the Southern Railway. The deposit, about sixty miles from Sydney, contains excellent brown ore, and is underlain by coal-seams, with good limestone in the neighbourhood. Smelting operations were carried on by a small syndicate at intervals for two or three years but were soon discontinued, and in 1859 the works were leased to Messrs. Latton & Hughes who built a new furnace, and five years later introduced hot-blast and erected puddling furnaces and rolling-mills. About 1875 the works changed hands again, and after some vicissitudes they appear to have closed down in 1877. Another enterprise, the Lithgow (Eskbank) Ironworks, was founded in 1874. Smelting operations were begun in October 1875 and were carried on intermittently for several years. The ore used was partly clayband occurring in the district, and partly brown and magnetic ores from Newbridge and Blayney. The greater portion of the pig iron was converted at the works into castings, bars, angle iron, and iron rails. But the operations were not financially successful, and after a few years the blast-furnace was dismantled. The Lithgow works were carried on for a short period by a party of workmen on the co-operative system, the rolling-mills being chiefly employed for re-rolling old iron rails. In 1885 the works were taken over by W. Sanford, and after that date considerable progress was made. Large quantities of scrap iron were worked up into bars and sheets; a sheet mill, a galvanising plant, and machines for the manufacture of railway spikes were erected. An open-hearth furnace was added to the plant, and in this furnace steel was manufactured for the first time in Australia. In 1908 the Lithgow Ironworks were purchased by C. H. Hoskins, and at that time the plant consisted of one blast-furnace with three stoves capable of making 700 tons per week, one 15-ton and two 4-ton basic new form Siemens furnaces, one 24-inch mill, reversing by means of clutches, which had never been worked and was useless, one 18-inch two-high pull-over mill, one 14-inch muck bar mill, one 14-inch two-high bar mill, and one small 9-inch three-high guide mill. With the exception of the blast-furnace and the 18-inch mill, which have been considerably altered, the plant has been entirely replaced by modern equipment. The manufacture of puddled iron, which was carried on in eight puddling furnaces, was abandoned, and the company concentrated on the production of steel. The company owns, besides, an engineering and cast iron pipe works at Sydney and at Rhodes, a suburb of Sydney, a colliery comprising 5000 acres of coal-field, with a coking plant at Dapto, on the coast, fifty-six miles distant from Sydney, and 400 acres of land have recently been acquired at Port Kembla, on the coast, eight miles distant from the colliery and coke-ovens, with a view to establishing a modern steelworks. The company is practically self-supporting as regards all its raw materials, as it owns iron ore properties in New South Wales and Tasmania, together with extensive coal properties and limestone deposits; also manganese ore properties at Grenfell, 156 miles west of Lithgow, with ore of sufficiently high quality for the manufacture of high-grade ferro-manganese. An additional coal-mine is being opened up at Lithgow, two miles from the works, consisting of about 3500 acres of good coking coal. The coal-seam is 10 feet thick at a depth of 300 feet, 6 feet of which is good coal with about 32 per cent. volatile matter and 8 per cent. of ash. The remaining 4 feet is inferior coal, mainly used for boiler firing. The iron ore properties are estimated to contain 80 to 100 million tons of good ore, and the ore at present is drawn from Tallawang, 100 miles north-west, from Carcoar, 80 miles south-west, and Cadia, 100 miles south-west of Lithgow. The ore from the first is a magnetite with 60 per cent. iron, and the two latter deposits supply red hæmatite containing 57 to 58 per cent. iron. The limestone is obtained from the company's own quarries, 25 miles west of the steelworks. Other deposits of red hæmatite are held with a view to using the ore at the projected new steelworks at Port Kembla. At the Lithgow Steelworks there is a battery of 95 coke-ovens of Belgian type, with a capacity of 1500 tons of coke a week, and the supply can be augmented from the coke-ovens at Dapto. There are two blast-furnaces, hand filled, with a combined capacity of 150,000 tons per year. Half of the iron produced is of foundry quality, the other half being sent direct in 30-ton ladles to the steel furnaces. Blast is supplied to the blast-furnaces by three Parsons' turbine blowers, the usual working pressure being about 10 lbs. per square inch. The open-hearth department consists of three modern basic furnaces of 50, 70, and 80 tons capacity respectively, and a fourth furnace of 80 tons capacity is in course of erection. The rolling-mill equipment comprises a 28-inch blooming and finishing mill and three bar mills, steam driven. All classes of carbon steel, including spring steel and material for the manufacture of small arms, are produced. The cast iron pipe and engineering works at Sydney and Rhodes are the largest in Australia, and are capable of producing 1500 tons of pipes per week.

The Broken Hill Proprietary Company in 1911 began to plan the establishment of ironworks. The company already owned the iron ore deposits of Iron Knob and Iron Monarch, the ore from which had hitherto been used as flux in the lead and zinc smelting industry. The site for the new works was chosen at the port of Newcastle, on the northern coal-field of New South Wales, the coal of which was highly suitable for coking. The limestone is obtained from a very large deposit in Tasmania close to deep water. The first blast-furnace was blown in in March 1915, and the first steel was made on April 9, while rail-rolling started a fortnight later. The starting of the works early in the war enabled the Government to complete the strategic line from Kalgoorlie in Western Australia to Port Augusta at the head of Spencer's Gulf, thus connecting by rail Perth, the capital, and Fremantle, the port of shipment of Western Australia, with all the large cities of South Australia, Victoria, and New South Wales. The company also furnished rails to South Africa to replace those taken up to supply equipment for France, also rails and shell bars to the British Government. Ship plates, bulb angles and joists were also supplied for the construction of ships in the United States. The plant now consists of a battery of 224 Semet-Solvay by-product coke-ovens of the recuperative type, with recovery of tar, sulphate, and benzol, two blast-furnaces 85 feet high, one furnace 90 feet, and one furnace 68 feet, the latter being for the manufacture of ferro-manganese. The ore-yard is spanned by two bridge unloaders, which deliver the ore and limestone to the stockpile or into a 50-ton car for distribution to the furnaces. The molten basic pig iron is conveyed direct to the steel furnaces, and the excess of metal is poured into a pig casting machine and stacked in the open-hearth stockyard. Foundry pig is also poured into another pig-casting machine and stacked according to analysis.

The open-hearth department has seven basic furnaces of 65-ton capacity and a 1000-ton mixer. The rolling-mill equipment consists of a 35-inch blooming mill, one 18-inch merchant mill, two smaller merchant mills, and a 28-inch rail mill, all steam-driven. A Morgan continuous rod mill adjoins the merchant mills and receives the product from the 18-inch mill. Steel ingots can be produced at the rate of 36,000 tons a month, and the rail mill has a capacity of 1000 tons per day of 80-pound rails. Plans have been prepared for the extension of the works to permit the conversion of 550,000 tons of basic iron into steel yearly, with additional mills to be electrically driven, the power being derived from blast-furnace gas.

There have also been considerable developments among the subsidiary iron manufacturing industries in Australia. The Austral Nail Company, Ltd., of Melbourne, has manufactured nails and barb wire for thirty years from imported material. In 1918 they began to draw their raw material supplies from the Broken Hill Proprietary Company's steelworks at Newcastle, and it was decided to erect a large modern wire mill at Newcastle near the steelworks, and to close down the Melbourne Mill. The new plant was put into operation in September 1918 on a limited scale. In January 1920 regular production was commenced, and during the first twelve months 45,000 tons of wire were drawn.

Early in 1921 Rylands Brothers, Ltd., of Warrington, decided to establish works in Australia for the manufacture of wire netting and the finer wire products. The amalgamation of the Austral Nail Company and the Australian interests of Rylands Brothers was effected under the name of Rylands Brothers (Australia), Ltd. The works are now equipped for the manufacture of all classes of plain wire, and of spring, coppered, and galvanised wire, nails, and barb wire. The new plant for the manufacture of wire netting is now installed, and the company is in a position to manufacture from 75,000 to 100,000 of mixed wire products per annum, ranging from heavy fence wire down to the finest gauges of tinned wires, including high-grade high-carbon wires such as are used for rope-making. The wire netting works will be capable of turning out from 10,000 to 20,000 miles of wire netting per year.

Lysaghts Newcastle Works, Ltd., have also been established for the manufacture of black sheets, galvanised plain sheets, and corrugated sheets. Eight sheet mills have been provided for, two of which are now in operation. The plant will be entirely electrically driven. The close annealing furnace is of the gas-fired continuous type, capable of dealing with 500 tons of sheets per week. The galvanising department can turn out 450 tons of corrugated sheets per week. The demand for steel corrugated sheeting was over 100,000 tons per year before the war, and as it is almost universally used for the roof of the ordinary dwelling-house the market grows as the population increases.

Czecho-Slovak Iron and Steel Industry (Iron and Coal Trades Review, September 8, 1922, vol. 105, p. 358). Of the 47 blast-furnaces in the former Austro-Hungarian Empire, 27 are in Czecho-Slovakia. Of these 10 are in Bohemia, 8 in Moravia, 3 in Silesia, and 6 in Slovakia. The total annual capacity of all Czecho-Slovak blast-furnaces is about 1¾ million tons. There are in Czecho-Slovakia 42 open-hearth furnaces, 5 basic Bessemer converters, and 3 Talbot furnaces, the total annual capacity of which is estimated to be 2,000,000 tons. The 16 rolling-mills of the State have a total normal capacity estimated at 2 to 2¼ million tons per annum.

Dornhecker, *The Development of the Italian Iron Industry by Extensive Application of Electrical Energy* (Stahl und Eisen, June 1, 1922, vol. 42, pp. 845–848). A list of the principal Italian steelworks using electric furnaces is given, with particulars of their type and capacity. The steel foundry of the Fiat Company is briefly described, with plans and sections of the plant.

B. Schapiro, *Russian Iron and Steel* (Iron Trade Review, September 7, 1922, vol. 71, pp. 647–650). In discussing the conditions in the Russian iron and steel industry, the author gives some interesting figures showing the coal and iron ore reserves. Figures of production of iron and steel for the period 1913–1920 and the number of furnaces existing before the war are also given.

W. L. Schurz, *Brazilian Iron and Steel Industry* (Report to the United States Bureau of Foreign and Domestic Commerce: Iron Trade Review, June 29, 1922, vol. 70, pp. 1861–1864, 1868: Iron and Coal Trades Review, August 4, 1922, vol. 105, pp. 155–156). The progress of the iron and steel industry in Brazil is reviewed. The basis of the industry is the vast stores of high-grade hæmatite and magnetite ore existing in the State of Minas Geraes, and to a lesser degree in several other States, including Sao Paulo and Parana. Though experts are convinced of the unsuitability of the low-grade domestic coal for smelting purposes, great hopes are held in Brazil for the adaptation of the new direct processes using pulverised coal. Charcoal made from eucalyptus wood is already being used in the production of pig iron.

E. A. Sperry, *Modern Blast-Furnace Plant on the Yangtse* (Iron Age, August 17, 1922, vol. 110, pp. 416–418). The new iron and steel plant which is being erected at Tayeh will consist of eight blast-furnaces with a capacity of over 3000 tons of pig iron per day, a steel plant, and adequate rolling machinery. The company operating the plant is the Tayeh Iron and Steel Co., and is a subsidiary of the Han-Yeh Ping Iron and Coal Co. A brief history of the company is given.

History of Iron.—L. Guillet and J. Cournot, *Réaumur*, 1683–1757: *His Life and His Work* (Revue de Métallurgie, Mémoires, August 1922, vol. 19, pp. 443). An account of Réaumur's life, and a lengthy abstract of his work entitled *L'Art de Convertir le Fer Forgé en Acier et l'Art d'adoucir le Fer Fondu* (The Art of Converting Wrought Iron into Steel, and of Softening Cast Iron), published in Paris in 1722, with reproductions of the original title-page and many of the illustrations. The Institute library possesses two copies of the original work.

II.—*BLAST-FURNACE SLAGS.*

Constitution of Blast-Furnace Slags.—C. Lemaire, *The Constitution of Blast-Furnace Slag* (Industrie Chimique, 1922, vol. 9, pp. 105–107). The author discusses the constitution and chemical composition of the slags obtained in the production of various grades of iron.

Manufacture of Slag Cement and Slag Bricks.—R. Grün, *The Conversion of Acid Blast-Furnace Slag into Basic Slag and Cement* (Stahl und Eisen, July 27, 1922, vol. 42, pp. 1158–1167). Portland cement can be manufactured from acid blast-furnace slags by the addition of lime and alumina to the hot slag which lacks these constituents necessary for making portland cement. It is important that the alumina should be added before the lime, as the mixture then becomes fluid with a low melting point, and easily takes up the lime. But as the lime increases the melting point rises, and the mixture is apt to become pasty unless means are provided for raising the temperature of the mass very considerably. It is preferable on that account, when converting acid slags of low hydraulicity, to aim at making blast-furnace cement (slag cement), which does not require the same proportion of lime. If the alumina is added first the mixture will remain fluid enough to absorb sufficient lime to form about 50 per cent. of the whole mixture, and a very good cement will result.

A. Guttmann, *Manufacture and Properties of Bricks from Blast-Furnace Slag* (D. Bauzeitung, April 29, 1922, p. 56).

III.—*DIRECT PROCESSES.*

Direct Production of Steel.—R. Whitfield, *The Production of Iron and Steel Direct from the Ore* (Iron and Coal Trades Review, July 21, 1922, vol. 105, p. 84). Careful consideration of the conditions necessary to a sound solution of the problem of direct production of iron and steel leads to the conclusion that only by the application of methods of gaseous reduction under suitable conditions can commercial success be attained. The Basset and Bourcoud processes are outlined.

Steel Direct from Ore by Basset Process (Iron Age, April 13, 1922, vol. 109, pp. 989–991). A lengthy abstract of the article by F. Wüst which appeared in *Stahl und Eisen*, December 22, 1921, vol. 41, pp. 1841–1848, giving a critical review of the Basset process.

Puddling.—E. C. Kreutzberg, *Manufacture of Puddled Iron Mechanically* (Iron Trade Review, August 10, 1922, vol. 71, pp. 365–367). The new mechanical puddler recently developed at the plant of the Titan Iron and Steel Co., Newark, New Jersey, is described and illustrated. It is the invention of H. D. Hibbard. Puddled balls ranging from 1000 to 1500 pounds are being produced daily in this furnace at the rate of one per hour. The principal feature of the furnace is a dam over which the charge of molten metal and oxide of iron is poured repeatedly. This pouring is accomplished by the oscillation of the furnace. The furnace is a cylindrical drum of steel plate construction having an outside diameter of 6 feet and a length of 5½ feet. It is placed with its axis in a horizontal position, and its ends terminate in trunnions which rest upon roller bearings supported in turn by a structural steel base. The interior of the furnace is lined with magnesite brick which is covered by a layer of sintered iron. The dam, which is also of magnesite brick, rests on the lining at the bottom and extends from end to end. Molten metal from the cupola is charged into the furnace through one of the trunnions, and the charge is completed by adding the requisite amount of roll scale. The furnace is oil-fired, the oil flame entering through the other trunnion. Oscillation of the furnace is accomplished through a worm gear by a reversing motor controlled from a switchboard alongside the furnace. The oscillating movement is continued after the iron has cleared in order to afford thorough distribution of the slag. After the sponge begins to form into a ball, the furnace is rotated for five minutes. The furnace is then brought to rest in the upside down position, and the top, which is a swinging door, is unfastened and the ball drops on to the conveyor leading to the squeezer. Tests of bar iron produced in this furnace show that the iron is equal in quality to the best wrought iron produced in present day practice.

Primitive Iron.—J. Myers, *Note on Pre-Roman Iron Bars* (Journal of Society of Chemical Industry, May 15, 1922, vol. 41, pp. 133–134 T). Thirteen iron bars were discovered recently upon the site of a prehistoric village on Worthy Down near Winchester, which on examination were considered to be pre-Roman iron in the form of currency bars. Seven of the bars were comparatively perfect. Their lengths varied from 32½ to 34$\frac{7}{10}$ inches, and their average weight 631·7 grammes. In form they are flat with squared edges, the extremity of the broader end being pinched in so that the two edges in some cases meet in the median line, forming a sort of hollow handle. The following is an analysis of the bars: Combined carbon 0·06, silicon 0·11, sulphur 0·014, manganese faint trace (in one specimen none), nickel faint trace, phosphorus 0·954 per cent. The composition is characteristic of a primitive iron directly reduced from ore in a pasty state. Micrographs of the iron are shown.

FOUNDRY PRACTICE.

Cupola Practice.—*A New Type of Small Cupola* (Foundry Trade Journal, June 22, 1922, vol. 25. p. 478). The cupola described is provided with a drop bottom and a loose removable well. The well is mounted immediately below the drop bottom and becomes a receiver, attached in such close proximity to the melting zone that a high temperature is maintained in it. In operation the well is lowered from the furnace on to a carriage, taken to the mould, and tapped out there, the well being used as a bogie ladle.

Innovations in Cupola Practice (Foundry Trade Journal, May 4, 1922, vol. 25, pp. 329–330). An illustrated description is given of the melting equipment at the plant of the Centrifugal Castings, Ltd., Kilmarnock. It consists of an ordinary foundry cupola, combined with an elevator charging device and an oil-fired receiver. The cupola is charged by means of a bucket type elevator discharging direct into a specially constructed shute leading through the ordinary charging door. Two tap-holes are provided, one leading into the receiver and the other for use in case of emergency. The receiver consists of a shallow hearth totally enclosed in refractory brickwork mounted on cast iron framing, the whole carried on wheels to enable the receiver to be moved away from the cupola for repairs. The receiver is equipped with a tapping spout and a special charging door. Four oil burners are provided of the low pressure air type, supplied with air from the fan-blower which supplies the cupola. In actual practice the bed of the cupola is charged on, and when starting from "all cold" the full complement of oil burners are lighted. The oil furnace is brought to a temperature sufficiently high to receive the molten metal, during which time the cupola is being charged. Melting is then commenced in the cupola, and the molten metal runs direct into the receiver. As the metal collects in the receiver and is withdrawn to meet the requirements of the foundry, the burner capacity is gradually reduced.

A. Poole, *Cupola Facts, Factors, and Fancies* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 1, 1922, vol. 25, pp. 404–405). Cupola practice is discussed with special reference to the quality of the fuel, temperature of melting zone, internal form of cupola, influence of atmospheric conditions inside cupola, and silica linings.

Y. A. Dyer, *Heat Factors Govern Melting* (Foundry, August 15, 1922, vol. 50, pp. 661–662). The author discusses the importance of thermophysics in melting, superheating, pouring and cooling of iron, and summarises the heat units expended in foundry practice in melting pig iron and average foundry scrap.

Hörnig, *Cupola Operations, Requirements in Coke and its Influence in increasing the Sulphur in the Metal* (Giesserei Zeitung, April 4, 1922, vol. 19, pp. 215–220). Modern cupola practice is discussed, using an air preheater.

H. Hermanns, *Melting Iron in a German Foundry* (Foundry, May 1, 1922, vol. 50, pp. 367–370). An illustrated description of the equipment and methods of the foundry of the Deutz Gas-Engine Co., Cologne, for the production of internal combustion engine cylinders. It is the practice to cast a number of different kinds of metal every day, the mixture varying as the heat proceeds. To handle this properly, charge tables are prepared indicating the order of the different mixtures with the names of the moulders who are to cast the several kinds of iron. A system of electric charge indicators is fixed between the cupolas for showing the kind of iron being melted at a given period during the run. The indicators also show the composition of the iron delivered by the furnace from time to time, and the class of castings to which it is adapted.

Y. A. Dyer, *Metal for Cast Iron Car Wheels* (Iron Age, June 1, 1922, vol. 109, pp. 1504–1506). The need for careful co-ordination of chemical and physical factors in the production of cast iron car wheels is pointed out, and the problems involved in mixing, cupola practice, moulding, melting, pouring, and annealing are discussed.

R. Moldenke, *Use of Machine-Cast Pig Iron* (Foundry, May 1, 1922, vol. 50, p. 375). The author briefly discusses the advantages in the use of machine-cast pig iron for foundry purposes.

O. Smalley, *Cast Iron and its Chemical Composition* (Paper read before the Institution of British Foundrymen : Foundry Trade Journal, May 4, 11, 1922, vol. 25, pp. 323–326, 343–345). The influence of various elements on the physical properties of cast iron, and the importance of casting temperature as a factor in the production of good castings are discussed.

E. Ronceray, *The Making of Castings without Feeding Heads* (Foundry Trade Journal, June 1, 1922, vol. 25, pp. 393–397). The author describes the practice of pouring castings without the use of feeding heads, a method which was originated by E. Saillot.

S. G. Smith, *Making Castings without Feeding Heads* (Foundry Trade Journal, August 17, 1922, vol. 26, pp. 140–141). The author discusses the general applications of the practice of pouring castings without feeding heads.

L. L. Vayda, *Use of a Blast Meter in Foundry Practice* (Paper read before the Pittsburgh Foundrymen's Association : Iron Age, June 8, 1922, vol. 109, pp. 1584–1586). The measurement of blast volume in cupola control is described.

Charging Machines for Cupolas (Engineer, June 30, 1922, vol. 133, pp. 727–728). A machine for charging cupolas has been designed by

Thwaites Brothers, Ltd., Bradford. It is in the form of an inclined hoist, and no platform at the top is required, and to instal it no alteration in the construction of the cupola is necessary. The hoist is motor driven, but may also be adapted for hand operation.

Electric Furnace Practice in the Foundry.—H. P. Abel, A. A. Liardet, and W. West, *Single-Phase Electric Furnaces* (Paper read before the West Yorkshire Metallurgical Society: Foundry Trade Journal, June 1, 1922, vol. 25, pp. 398–401). The authors discuss the design and operation of single-phase electric furnaces for the production of steel castings.

C. W. Francis, *The Electric Furnace for the Foundry* (Iron Age, July 27, August 3, 10, 17, 31, September 21, 1922, vol. 110, pp. 201--202, 277–278, 345–346, 421–422, 525–526, 725, 763). A series of articles dealing with electric furnace practice in the production of steel castings. The chief controlling items in operating costs are also discussed.

A. Stromboli, *Fiat Electric Steel Furnace* (Chemical and Metallurgical Engineering, July 5, 1922, vol. 27, pp. 28–30). The furnaces at the Fiat works in Turin are described and illustrated. The furnace is of the "fast" type, and has a perfectly tight roof maintained by means of a special economiser, details of which are given. It has only two openings, one for charging and removing the slag and the other for pouring, and can be rotated for either purpose. The electrode holders are hermetically sealed by packing rings, thus absolutely preventing air circulation through the furnace, or oxidation of the electrode, and hence greatly reducing electrode consumption. After a run of twenty-one heats of 5 tons each the electrode consumption only worked out at 2·85 kilogrammes per ton of steel made. The air-tight construction further enables the use of cast iron or other carbonising agent in the charge to be dispensed with. The furnace is a 3-phase furnace with three electrodes arranged vertically above the bath, the arc being made to impinge directly on the metal. High tension current (21,000 volts) is transformed to 75 to 120 volts by a static transformer, and the time taken in working a 5-ton charge, from beginning to end, is two hours, with a power consumption averaging 460 kilowatt-hours per ton of steel cast.

H. Vogl, *The Suitability of the Electric Furnace for the Production of Ingot-Moulds and Malleable Castings* (Mitteilungen a. d. Kaiser-Wilhelm-Institut für Eisenforschung, 1922, vol. 3, No. 2, pp. 77–98). Ingot moulds cast from grey cast iron refined in the electric furnace are found to have a greater length of life than ordinary ingot moulds. The metallurgical operations in melting the charge and casting the moulds are described. The electric furnace can also produce an excellent material from which to make malleable castings.

H. R. Simonds, *Foundry Employs Electricity for Melting and Annealing* (Iron Trade Review, June 1, 1922, vol. 70, pp. 1567–1570). An illustrated description is given of the equipment of an American foundry which has recently installed electric melting and annealing furnaces for the production of iron and steel castings.

J. A. Mathews, *The Present Status of the Electric Furnace in Refining Iron and Steel* (Paper read before American Iron and Steel Institute, October 27, 1922). The author gives a general review of the expansion of electric steel making. There are now nearly 1000 electric furnaces installed in America and Europe, nearly half of them being in the United States and Canada. Italy has about 180 electric furnaces for steel-melting, 27 of which are from 15 to 25 tons capacity. In 1921 her tonnage of electric steel was second only to that of the United States. The annual productive capacity in Italy is about 1,000,000 tons, and the furnaces can be worked rapidly with great economy of electrode consumption.

Steel Foundry Practice.—D. D. MacGuffie, *General Steel Founding* (Metal Industry, July 21, 28, August 4, 11. 18, September 1, 8, 29, 1922, vol. 21, pp. 59–61, 87–88, 109–111, 115, 131–132, 136, 155–157, 201–203, 225–227, 301–304). A general article outlining the methods for the production of steel castings. The crucible process, Tropenas and Stock converters, open-hearth and electric furnace practice, foundry equipment, moulding sands, and moulding practice are dealt with.

L. J. Barton, *Alloy Castings from Electric Furnaces* (Iron Age, September 28, 1922, vol. 110, pp. 784–786). The production of nickel, chromium, and chrome-nickel steels in a basic electric furnace, their properties and heat treatment are briefly discussed.

F. Darley, *Production of Steel Castings* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, September 7, 14, 1922, vol. 26, pp. 199–202, 225–226). The author discusses the most important factors in the production of castings for turbine parts.

H. Bradley, *The Manufacture of Light Steel Castings* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 22, 1922, vol. 25, pp. 467–468). The author discusses a number of points relating to the manufacture of steel castings.

J. Jefferson, *Some Notes on Steel Castings* (Journal of the West of Scotland Iron and Steel Institute, Session 1921–1922, vol. 29, pp. 53–59). The effect of composition, casting temperature, and heat treatment on the properties of steel castings is discussed.

Semi-Steel.—D. McLain, *The Metallurgy of Semi-Steel* (Foundry Trade Journal, August 10, 1921, vol. 26, pp. 110–114). The greatest developments in grey iron foundry practice are traceable to the introduction of steel scrap in cupola mixtures. The use of steel has been questioned on every side, but all such theories were exploded when it was proved that carbon would be absorbed by the steel up to the saturation point, and that manganese above a certain point assisted in increasing the saturation point of iron for carbon. Photomicrographs are given of specimens showing the mistake of pouring castings of different sections from one mixture.

J. Cameron, *Semi-Steel* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 29, 1922, vol. 25, pp. 495–500). The author discusses at length the properties and manufacture of semi-steel, produced in the cupola, using coke as fuel and the usual air-blast.

J. Hogg, *Melting Steel and Cast Iron together in the Cupola* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, August 24, 1922, vol. 26, pp. 160–162). Practice in the manufacture of semi-steel is described.

E. J. Lowry, *Steel Scrap in Cupola Iron Mixtures* (Iron Age, August 10, 1922, vol. 110, pp. 337–338). The author discusses the factors to be considered in the melting of steel scrap in the cupola, and the more important characteristics of semi-steel are dealt with.

Foundry Sands.—C. W. H. Holmes, *An Investigation on the Factors influencing the Grain and Bond in Moulding Sands.* (This Journal, p. 61).

H. A. Schwartz, *Sand Screen Tests* (Paper read before the American Foundrymen's Association: The Foundry, September 15, 1922, vol. 50, pp. 752–756). Investigations indicate the effect of different shapes and sizes on perviousness of moulding sand. The method of testing is described, and the following conclusions are drawn: Sands of absolutely uniform grain size are the most pervious. The relation between grain size and perviousness of sands is too complicated to permit drawing any conclusions. The perviousness can be readily and cheaply determined by direct experiments. The sieve test of sand is of academic interest only and means practically nothing in a study of the commercial properties of moulding sand.

J. H. Watson, *Some Notes on Moulding Sands* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, September 14, 1922, vol. 26, pp. 211–216). The importance of suitable moulding sand as a contributory factor in the production of good castings is discussed. The chief properties which enable a sand to function properly are refractoriness, venting qualities, strength of bond, and size of grain. There is a common impression that a sand showing on analysis a reasonably high silica content will be refractory. Though silica is the commonest constituent of rocks, it is most frequently in chemical combination with other substances, and, combined in this way and forming a mineral ingredient of moulding sand, it does not possess the same degree of refractoriness as when in the free or uncombined condition, when it is present as quartz.

H. Kalpers, *The Preparation of Moulding Sand* (Engineering Progress: Foundry Trade Journal, July 6, 1922, vol. 26, pp. 13–14). The actual preparation of the sand comprises the preparation and mixing of the new sand, of the old sand, and of the coal-dust. The ratio of combining these three components depends primarily on the purpose for which the sand is to be employed and is determined by the question as to whether grey cast iron, malleable iron, cast steel, or non-ferrous metals are concerned.

E. F. Cone, *Solving Sand Problems in a Steel Foundry* (Iron Age, April 13, 1922, vol. 109, pp. 985–988). The methods of handling the sand at a steel foundry where only small castings are produced are described and illustrated.

Properties of Steel Sands (Iron Trade Review, July 13, 1922, vol. 71, pp. 103–106). An outline is given of the methods of research adopted at the plant of the Sivyer Steel Casting Co., Milwaukee, for studying the permeability and strength of facing sands.

Moulding and Core Making.—J. Varlet, *History of Loam Moulding in the Province of Liége* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 22, 1922, vol. 25, pp. 473–477). The origin of loam moulding dates from 1846, in which year it was practised for the first time in the Gomree Foundry. It was not until 1870 that it began to be generally adopted and that many foundries decided to produce engine cylinders, condensers, and steam-engine parts by this method. The present day methods of loam moulding are described in detail.

Using Metal-Faced Cores in Cylinders (Foundry, August 15, 1922, vol. 71, pp. 684–685). The use of metal-faced cores for the production of motor-car cylinders is described. A preparation is employed to cover the metal face of the core to prevent the metal from chilling, but no particulars are given regarding its character or composition. Cylinders cast on these cores, when finished, present a dense, smooth surface indicating a uniform crystallisation brought about by a thorough breaking-up and even distribution of the graphitic carbon. Samples cut from 200 cylinder blocks showed an average Brinell number from the top to the bottom of the cylinder of 200.

A Modern Installation of Drying Ovens (Iron and Coal Trades Review, August 18, 1922, vol. 105, pp. 223–224). Particulars are given of the Lane system of heating mould and core drying ovens. A battery of ovens is heated from a central firebox situated below ground level with blast supplied by a fan. The air from the fan is driven into the pit and warmed, just sufficient air being allowed to pass through the fuel bed to maintain a red glow. By a series of flues, large quantities of air are heated, further air being allowed to pass over the fuel. A special chamber provides for the auxiliary air and also serves as a mixing chamber for the air and gas. The heated air and products of combustion from the firebox are drawn into a large flue, which acts as a reservoir from which heat can be tapped when required. Regulating dampers are fixed at the back end of the chambers from which the heat travels in the direction of the chamber doors. At the front of each chamber perforated plates and dampers are attached to a series of flues, the arrangement of which provides such control over the heated air that an absolute uniformity of temperature is obtained throughout the whole of the drying chamber. The air ultimately passes into a common outlet flue and thence to the stack.

General Foundry Practice.—C. Irresberger, *Roll Casting* (Giesserei Zeitung, June 6, 13, 20, 27, 1922, vol. 19, pp. 342–344, 354–358, 371–374, 381–386). The author discusses the manufacture of steel rolls and chilled rolls, the most suitable composition, methods of moulding and subsequent treatment after casting.

B. H. Arnold, *Iron for Piston Rings* (The Foundry, September 15, 1922, vol. 50, pp. 748–751). The author describes the use of an oil-fired regenerative furnace for melting and refining grey iron for the production of piston rings. The furnace, which is of cylindrical form and equipped with pyrometers, produces a satisfactory metal.

C. Irresberger, *Mass Production of High-Quality Piston-Rings* (Stahl und Eisen, June 1, 1922, vol. 42, pp. 841–845). The article is practically a translation of H. Cole Estep's paper on the manufacture of piston rings (Foundry, November 15, 1921, pp. 879–887). The composition that has given the most satisfactory results for piston rings is stated, and the casting of the rings by the centrifugal process is illustrated and described.

Casting Chevrolet Cylinders (Foundry, July 15, 1922, vol. 50, pp. 565–569, 579). An illustrated description is given of the methods employed by the Detroit Foundry Co., Detroit, for the production of motor car cylinders. Details of core-making, venting, method of setting and adjusting the cores, are described, together with the operations involved in making the mould.

A. L. Ross, *Moulding a Trunk Casting in Loam* (Foundry Trade Journal, July 6, 1922, vol. 26, pp. 15–16). A simple method is described for moulding a trunk or cross-head guide casting which is used for modern winding engines.

Fittings made on Production Basis (Foundry, May 1, 1922, vol. 50, pp. 359–365). Simple devices in the shape of lifting plates and core prints which reduce the costs of moulding and insure a more uniform product in the production of cast iron pipes and fittings are described and illustrated.

H. R. Simonds, *Makes Valves in New Foundry* (Foundry, June 1, 1922, vol. 50, pp. 431–435). An illustrated description is given of the plant and methods for the production of steel valve castings at the foundry of the Chapman Valve Co., Indian Orchard, Massachusetts.

S. G. Smith, *Steam Turbine Parts* (Foundry Trade Journal, September 7, 1922, vol. 26, pp. 192–194). The author describes the method of moulding cast iron diaphragms for steam turbines. A suitable composition of iron used for these castings is: combined carbon 0·67, graphitic carbon 2·95, silicon 1·42, manganese 0·66, phosphorus 0·50, and sulphur 0·09 per cent.

Making Flexible Jointed Pipe (Foundry, August 1, 1922, vol. 50, pp. 616–621). The equipment and methods of moulding and casting flexible jointed water pipes are described and illustrated.

W. E. Jewell, *Cast Iron Pots made in China* (Foundry, June 1, 1922, vol. 50, pp. 444–447). The author describes the native foundry methods and devices in Shingishu Korea, for the production of cast iron pots. The cupola usually is about 5 feet high, made in two sections, a bowl provided with trunnions forming the bottom and a plain cylinder forming the top section. The motor for the fan is a compound gear mounted on a small scaffold and driven by two double crank arms manned by four coolies. The cupola is tipped for pouring and drained of both slag and iron through the open breast which is left open during the progress of the heat.

International Foundry Exhibition (Foundry Trade Journal, June 15, 1922, vol. 25, pp. 430–446; Iron and Coal Trades Review, June 23, 1922, vol. 104, pp. 930–934). An account is given of some of the exhibits at the first exhibition solely devoted to the requirements and output of the foundry industry ever held in this country. The exhibits were comprehensive in character, moulding machines and cupolas being particularly represented. The exhibition was held in Birmingham.

Centrifugal Castings.—F. E. Hurst, *Centrifugal Castings* (Journal of the West of Scotland Iron and Steel Institute, Session 1921–1922, vol. 29, pp. 38–48). The manufacture and properties of centrifugal castings is discussed. The composition of some typical castings made by this process is shown, together with the results of tensile and wear tests. The structure of centrifugal castings is also discussed.

H. Illies, *The Manufacture of Centrifugal Castings* (Giesserei Zeitung, September 5, 1922, vol. 19, pp. 507–509). A description of the practice in casting pipes by the centrifugal method.

L. Cammen, *Chromium Alloy Steel Cast Centrifugally* (Iron Age, September 14, 1922, vol. 110, p. 655). A photomicrograph of high carbon chromium steel cast centrifugally and heat treated shows that the structure of the metal is purely pearlitic, no excess of cementite being present; the pearlitic grains are small notwithstanding the fact that the casting has not been subjected to any mechanical working. The most likely explanation is that it is the mechanical stirring due to the rapid rotation of the mould that affects the grain size, and possibly also the powerful impingement of hot particles of the metal on the layer next to it outwardly; then, in the process of freezing, this impingement may prevent by purely mechanical means the growth of the crystals and the peculiar ingot dendritism.

N. Lilienberg, *Centrifugal Casting* (Blast-Furnace and Steel Plant, July 1922, vol. 10, pp. 375–379). The manufacture of centrifugal castings should preferably be carried out in vertical moulds rather than in horizontal moulds as is customary, and some theoretical calculations necessary for the vertical method are given. Among the articles which could be advantageously produced by centrifugal casting vertically are projectiles and sleeves for shrinking over the explosion chambers of field-guns. The manufacture of these is much cheaper than by the present elaborate process.

Malleable Castings.—A. Phillips and E. S. Davenport, *Malleableising of White Cast Iron* (Paper read before the American Institute of Mining and Metallurgical Engineers, New York Meeting, February 1922, p. 23). Discusses the thermal critical points of white cast iron and of malleable iron, the changes produced in tensile properties and microstructure by annealing at different temperatures from 760° to 1100° C., and the relation of thickness of wall section of hard iron to the microstructure and tensile properties under normal annealing conditions. Notes are also given of the mechanics of graphitisation of normal white cast iron quenched after various periods of annealing at approximately 800° C. From experiments carried out the Ac1 point of iron with 2·4 per cent. of carbon and 0·90 per cent. of silicon was found to be at 765°. Annealing seems to permit considerable latitude with respect to temperature without serious loss of tensile strength.

E. Touceda, *American Methods of Manufacture of Malleable Iron Castings and some Data in Connection with the Finished Product* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, July 20, 27, Aug. 3, 10, 17, 1922, vol. 26, pp. 50–53, 75–77, 102–106, 122–124, 142–144). The author discusses American practice under the following headings: The lay-out of a malleable plant, the design of reverberatory furnaces for the production of white iron castings, the metallurgy of melting, sampling, the annealing process, heat treatment, essential features of annealing ovens, oven control, machining properties, and shrinkage of castings.

T. Levoz, *The Production of Malleable Castings and the Triplex Process* (Fonderie Moderne, June 1922, pp. 169–173). Discusses the composition and properties of malleables produced by triplex and other processes, and the production of malleable castings in continuous electrically heated furnaces.

P. Dwyer, *Brass Firm makes Malleable* (Foundry, July 1, 1922, vol. 50, pp. 523–528). An illustrated description is given of the layout of the new foundry of the Ohio Brass Co., Mansfield, Ohio, for the production of malleable iron castings.

E. K. Smith, *Annealing Pots* (Iron Trade Review, June 22. 1922, vol. 70, pp. 1805–1806). The annealing of malleable castings without packing is dealt with. Annealing pots having flanges at the top and bottom are used. The pots are stacked one on top of the other, the joint between each box being well luted to prevent gases from entering and attacking the castings. The temperature must be kept low to prevent warping of thin castings.

R. Stotz, *The Standardisation of Malleable Castings* (Giesserei

Zeitung, May 16, 23, 1922, vol. 19, pp. 301–303, 319–322). The article discusses the possibilities of prescribing standard conditions as regards composition, tensile properties, and methods of testing malleable castings, and gives a series of questions to be circulated to all German producers of malleable castings, for the purpose of eliciting opinion as to limits of phosphorus and sulphur, the best method of testing tensile strength and elongation, the best form of test-bar, whether test-bars are really requisite, or whether the test should be performed only on actual castings, the specific weight, and what contraction should be regarded as normal.

Safety in Foundries.—R. W. Patmore, *Safety Work in Foundries* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 22, 1922, vol. 25, pp. 464–467). The causes of accidents in foundry operations and their means of prevention is discussed.

PRODUCTION OF STEEL.

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I.—*PROCESSES OF STEEL PRODUCTION.*

The Bessemer Process.—B. Versen, *Note on the Design of Basic Bessemer Converters* (Stahl und Eisen, July 20, 1922, vol. 42, pp. 1125–1126). In order to promote the circulation of the metal in the bath and to reduce the amount of metal ejected during the blow, it is recommended that the cross-sectional area of the converter at the level of the bath should not be less than three and a half times the area within the outermost ring of nozzles. The blowing pressure should not exceed the static resistance of the metal by more than half an atmosphere. A pressure of 1¼ atmospheres is sufficient in a converter of ordinary size.

F. Hartig, *The Electrically Driven Blower at the Peine Rolling-Mills* (Stahl und Eisen, July 20, 1922, vol. 42, pp. 1119–1124). An illustrated description of the electric motor with diagram of connections, and the blower, capable of delivering 900 cubic metres per minute at 94 revolutions per minute at a pressure of 1·65 to 2·5 atmospheres.

S. R. Robinson, *Tropenas Converter for Making Steel* (Blast-Furnace and Steel Plant, May 1922, vol. 10, pp. 282–284). The Tropenas process differs from the Bessemer in that the air is blown on to the surface of the metal in the converter instead of through the bottom. The process consists in melting a mixture of low phosphorus pig iron and steel scrap in an ordinary cupola, transferring this metal to a converter in which the blast of air is introduced through tuyeres so adjusted that the blast impinges on the surface of the metal. It is upon adjusting of the tuyeres that the entire operation depends. They should at all times be perfectly level and in line with each other. They are usually made by ramming ganister around 1¼-inch pipe or rod and withdrawing the rod, or the pipe may be rammed up in place and allowed to remain in the lining. Seven tuyeres are used in the 2-ton converter, which is lined either with silica brick or rammed ganister. The process of the conversion of the change which is very similar to the Bessemer process is fully described.

The Talbot Process.—*The Talbot Process compared with other Processes* (Iron and Coal Trades Review, August 4, 1922, vol. 105, p. 146). A translation is given of the article by J. Puppe which appeared in *Stahl und Eisen*, January 5, 12, 1922, vol. 42, pp. 1–10, 46–54.

The Open-Hearth Process.—A. D. Williams, *Design of Open-Hearth Furnaces* (Iron Age, April 20, May 11, 1922, vol. 109, pp. 1075–1076, 1279–1281). Port areas and velocities as affected by pressures, chimney height, loss of heat through leaking brickwork and convection currents, and waste heat boilers, are discussed.

I. A. Billiar, *Design of Open-Hearth Roof* (Iron Trade Review, May 18, 1922, vol. 70, pp. 1407–1408). The use of a series of cooled pipe trusses for supporting the roof and automatically providing for its contraction and expansion is shown. There are alternate rows of hanger and spanning bricks and a series of skew-back plates each connected to a weighted lever in order to produce a slight compressive stress in the roof. Each transverse row of bricks has its independent plate and weighted lever. When the bricks expand transversely the row lengthens and presses the plate outwardly, thus providing room for the increased length. The weight merely moves upwards and keeps a constant force on the row. During contraction the reverse occurs ; this same force keeping the bricks close together, preventing leaks and spalls from dropping.

R. J. Sarjant, *The Scientific Principles of Furnace Design* (Fuel Economy Review, May 1922, vol. 2, pp. 16–19). The author outlines the fundamental principles underlying the design and operation of metallurgical furnaces.

W. C. Bulmer, *Gas and Air Valves for Open-Hearth Furnaces* (Paper read before the American Iron and Steel Institute, May 26, 1922, 32 pp.). The chief requisites of a proper valve are an effective seal and an unrestricted passage. From investigation of existing installations it may be stated that the effective draught in the flue leading from the checkers will seldom be over 50 per cent. of that found on the base of the stack. At the furnaces at South Chicago, when measurements were taken in the flue on each side of the gas valves, there was found to be a frictional loss amounting to 52 per cent. of the stack draught. This is not unusual, as in some installations the effective draught in the checker flues has been found to be as low as 30 per cent. of that of the stack, due to the smallness of the valve and the turns leading to and from it. Many types of valves have been designed, and the following are the kinds generally in use : Slide or damper, butterfly, mushroom and movable hood, any of which may be classed as refractory, water cooled, and water sealed. Water seal is the most perfect method that has yet been devised for prevention of leakage, but the great defect of this type of valve lies in the water evaporation that takes place from the basin. The passing hot gas picks up the vapour and is cooled to an appreciable extent. At each reversal more or less water is splashed into the gas flues and causes deterioration of the brickwork. Another objection is that the basin is always liable to leakage owing to the cracking of the seat, and it may happen that a negative pressure will cause a portion of the water to syphon from the basin into the flue. The water-cooled slide with inclined seat has proved to be the most satisfactory type of valve that has yet been designed.

A number of drawings are appended to the paper showing early and modern types of open-hearth furnace valves, including the McConnell reversing valve; the Treat water-cooled gas reversing valve; the McKennan valve; the Knox and the arrangement of flues in connection with it; the Ahlen; the Monroe; the Blair and the arrangement of flues in connection with it; the Forter reversing valve; the Schild gas and air reversing valve and the Schild revolving gas reversing valve; the Dyblie and the Isley valve.

C. L. Kinney and G. R. McDermott, *The Thermal Efficiency and Heat Balance of an Open-Hearth Furnace* (Paper read before American Iron and Steel Institute, October 27, 1922). An investigation is described, which was made to determine the efficiency and heat balance of a typical open-hearth, and on the basis of the data obtained a design of a 100-ton furnace is shown, embodying certain improvements in connection with the regenerators and gas and air ports.

E. F. Cone, *Making Steel without Using Pig Iron* (Iron Age, September 7, 1922, vol. 110, pp. 585–586). The steel-making process employed by the Central Iron and Steel Co., Harrisburg, Pennsylvania, is described. High-grade basic open-hearth steel is produced entirely from scrap. The distinguishing feature of the process is the maintenance of a high residual manganese throughout the period of the heat. The charge is made up of scrap steel and scrap iron in proportions varying from 60 to 90 per cent. of the former and from 40 to 10 per cent. of the latter, carbon in the form of coal, coke, or charcoal, and high-grade manganese ore. About 2 to 2½ tons of manganese ore is used in a 90-ton heat.

W. J. Priestley, *Effect of Sulphur and Oxides in Ordnance Steel* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, vol. 67, pp. 317-340). The author describes the behaviour of steel made by the duplex process, in which cold charges of pig iron and scrap were melted in a basic open-hearth furnace and dephosphorised, and the subsequent deoxidation and desulphurisation carried out in basic-lined electric furnaces. The presence of sulphur and of oxides, while not greatly influencing tensile longitudinal tests, had considerable influence in weakening the steel in transverse sections. The results are given of tests on steels with varying percentages of sulphur and phosphorus, the proportion of other elements being kept constant.

E. Maurer and S. Schleicher, *The Chemical and Thermal Changes in Open-Hearth Fuel Gases due to Preheating, especially in the Presence* *of Tar Vapours* (Mitteilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1922, vol. 3, No 2, pp. 59–76). An investigation of the changes in gases from the point of entry into the main to the point of passing through the furnace ports. Tar-free gases (blast-furnace and coke-oven gas) and gases containing tar (producer-gas from brown-coal briquettes) were studied, and from elaborate calculations formulæ have been derived by the aid of which the changes in the gases can be followed as they pass from the main to the ports. The cause of the loss of heat value is due to the exothermic reactions and to the dissociation of carbon. Water vapour counteracts the dissociation, as it regasifies the separated carbon. The carbon of brown-coal gas is much more readily regasified than that of coke-oven gas, and on this account brown-coal gas may have a higher calorific value after heating than before.

H. F. Miller, Junr., *Methods of Using Fuel in Open-Hearth Furnaces* (Paper read before American Iron and Steel Institute, May 26, 1922, 8 pp.). Experiments in changing the design of ports and uptakes of oil-fired furnaces and furnaces fired with natural gas are shown to have led to great improvement in the conditions of combustion of the fuel within the furnace.

L. Fähnrich, *Determination of Heat Losses in Metallurgical Furnaces* (Elektricität und Maschinenbau, December 4, 1921, vol. 39, pp. 597–599). A general discussion of the factors to be considered in determining the heat losses in metallurgical furnaces.

F. Clements, *British Siemens Furnace Practice* (Revue de Métallurgie, Mémoires, August 1922, vol. 19, pp. 469–498). A complete translation into French of the paper presented under this title before the Institute in May 1922, with reproductions of all the plates and tables (*Journal of the Iron and Steel Institute*, 1922, No. I. pp. 429–447).

H. D. Hibbard, *Leaves from a Steel Melter's Notebook, IV.* (Iron Age, May 4, 1922, vol. 109, pp. 1219–1220). The author relates his experiences in the operation of open-hearth furnaces using natural gas, and the early difficulties attending the supply of air to the furnaces.

Electric Steel Furnace Practice.—K. Kerpely, *The Heroult Furnace and its Working* (Giesserei Zeitung, August 29, September 5, 1922, pp. 487–491, 509–513). A general description of the construction of the Heroult furnace and of the metallurgical operations involved in its working.

R. Sylvany, *Developing an Electric Furnace* (Iron Trade Review, July 6, 1922, vol. 71. pp. 33–34). The author discusses the fundamental principles governing the design of electric furnaces, and describes the Levoz furnace.

M. Guédras, *The Construction of Electric Steel Furnaces* (Technique Moderne, 1921, vol. 13, pp. 497–501).

O. Brophy, *Circulation of Molten Metal by Means of Electrodynamic*

Forces (Chemical and Metallurgical Engineering, September 6, 1922, vol. 27, p. 489). Three important electro-dynamic forces may be used to circulate molten metal in the electric furnace. The "pinch" effect due to the fact that conductors carrying currents in the same direction attract each other may shortly be defined as the action of a current upon its conductor, in this case metal, the circulation of which is thus promoted. The "corner" effect, due to a force being set up when a liquid conductor carrying a current is made to turn an angle, shortly defined as the action of a current upon a conductor in another part of the same circuit, has the effect of making the force strongest at the apex of the angle, and so has the same result. Finally the "motor" effect—the action of a current in one circuit upon the current-carrying conductor of another circuit—has a wider effect than the two former, which are more localised, and if the circuit be properly designed will manifest itself in every part. It is this "motor" effect which was detrimental in the old open channel induction furnace as it tended to repel the molten metal from the primary coil towards the outside, when the primary was placed inside the secondary. Its force was so great that in, for example, an 8-ton Kjellin furnace, the bath became inclined to as much as 24°, the slag thus attacking the refractories.

W. J. S. Green and S. S. Green, *Electric Tool Steel Melting Practice* (Iron Age, April 13, 1922, vol. 109, pp. 999–1001). The authors review the major aspects of the three following important questions as they affect the manufacture of high-grade tool steel: (1) Acid versus basic bottom, (2) liquid versus cold charges, and (3) double versus single voltages. They recommend basic bottoms, cold charges, and double voltages of 115 to 125 high and 75 to 85 low.

H. W. Gillett and E. L. Mack, *Experimental Production of Certain Alloy Steels* (United States Bureau of Mines, 1922, Bulletin 199). The production of small heats of alloy steels on an experimental scale is dealt with. The construction and operation of the small indirect-arc furnace used in the experiments are described in detail. The report deals only with the preparation of the various steels, and with the recovery and the segregation of the different alloying elements. Some of the steels were of rather unusual composition, many being nickel steels high in silicon, or steels higher in various alloying elements than is common. As the composition of many of the steels is suitable only for special uses, no direct general conclusions can be drawn as to the value of zirconium, titanium, uranium, boron, and cerium as true alloying elements in commonly used types of steels. The results so far obtained in various physical tests of the steels covered by the report, in which these elements are present in appreciable percentages, have not in general been promising; nor have they been as good as those of similar steels of the series without these elements. Even in small ingots of 50 to 100 pounds, notable segregation of uranium, zirconium, or cerium generally appears when over about 0·5 per cent. of the first, or about 0·3 per cent. of either of the two latter, is present. Uranium and especially zirconium alloys used to introduce these elements into steel should apparently be as free from carbon as possible. Alloys of zirconium with silicon or nickel, or both, give fair recoveries of zirconium.

Titanium does not segregate as readily as zirconium, and its recovery from the ferro is higher; but in large amounts it is likely to segregate, and its recovery is not usually quantitative, although it may be quantitative if it is protected by a more readily oxidisable element, such as zirconium. Although these elements are readily oxidised, none of them appear to be as efficient as aluminium or vanadium in degasifying "wild" steel. Boron is almost quantitatively recovered when added at the end of the heat, and may be added at the start of the heat without great loss. In the amounts studied up to 0·6 per cent., no appreciable tendency to segregation was noted.

E. F. Russ, *A New Device for the Control of Electric Arc Furnaces* (Giesserei Zeitung, October 3, 1922, vol. 19, pp. 575–577). A new device for regulating the adjustment of electrodes in arc furnaces is described. The mechanism is operated hydraulically and is said to be extremely sensitive.

Electrodes.—C. L. Mantell, *Technology of the Carbon Electrode Industry* (Chemical and Metallurgical Engineering, July 19, 26, August 2, 9, 16, 23, 1922, vol. 27, pp. 109–112, 161–165, 205–210, 258–264, 312–318, 353–359). A series of articles dealing with every phase of electrode manufacture, commencing with the history of Sir Humphry Davy's earliest experiments with the electric arc in 1800, when simple charcoal electrodes were used. The raw materials of the present industry are body materials, which include coal and coke, graphite charcoal, lamp-black and amorphous butts from electrothermic work; binders, and certain miscellaneous substances which enter the manufacturing processes. Petroleum coke is the most important body material, and the methods by which it is obtained are described. For the purest electrodes petroleum coke is used alone. For lower grades anthracite is used, mixed with it. The sulphur content must, in any case, be as low as possible. The binding materials employed are tar, electrolytic pitch, and ordinary pitch. Analyses are given and the properties necessary are discussed. The first stage in the manufacture of electrodes is calcination of the body materials, which facilitates their being ground and moulded, dispels volatile matter which might render the electrodes porous, and reduces resistivity. It also causes shrinkage and thus increases density. Electric calciners or vertical gas retorts are employed. Preheated charges and recovery of by-product gases constitute the latest advances in calcining practice. Of the retorts described the Woodall-Duckham and the Glover-West are the most frequently employed. The subsequent operations of grinding, mixing, moulding, and extrusion are then dealt with at length.

Moulding usually confers greater density than extrusion, which is, however, an easier operation. A typical extrusion plant is described and illustrated, and particulars are given of the modes of inspecting and grading the product, with a list of the defects met with in practice and hints as to how to avoid them. The extruded or moulded electrode is then baked, which greatly increases its tensile strength and its conductiveness, the distillation " cracking " products of the binder having these effects on the material. The furnaces used are electric and care has to be taken that they do not foul owing to the accumulation of pitch and tar distilling from the binders used and settling on the bottom of the furnaces. The thicker therefore the packing material layer the better the insulation. Gas-fired baking furnaces are also used. The final stage in the manufacture of electrodes is the cleaning, for which several methods are in vogue, after which the finished carbons are inspected, machined by means of high-grade tool steel, particularly in the case of good amorphous electrodes which are dense and difficult to machine, packed and shipped. The tensile strength of amorphous electrodes is 50 per cent. higher than that of graphitic electrodes of the same diameter. Ordinarily, however, graphitic electrodes are much purer. The qualities are not competitive, as the field for amorphous electrodes is in electrothermal work, costing but one-third to a quarter as much as graphite-electrodes which are used in electrometallurgic deposition processes in the manufacture of gold, copper, and nickel.

C. W. Söderberg and M. Sem, *Söderberg Self-Baking Continuous Electrodes* (Chemical and Metallurgical Engineering, June 21, 1922, vol. 26, pp. 1178–1182). The authors outline the process of manufacture, and summarise the advantages in the use of the Söderberg electrode. The electrode is built, baked, and renewed without any interruption in operating the furnace.

E. F. Russ, *Electrodes for Arc Furnaces* (Giesserei Zeitung, May 30, 1922, vol. 19, pp. 332–335). Amorphous carbon electrodes are universally used in electric arc furnaces in Germany. The various methods adopted for sealing the opening in the furnace roof through which the electrodes pass are illustrated and described.

E. F. Russ, *Carbon Electrodes and their Manufacture* (Giesserei Zeitung, August 29, 1922, vol. 19, pp. 493–497). The method of manufacture of electrodes at the electrode factory at Rauxel is illustrated and described.

A. Thau, *Production of Coke with Low Ash* (Stahl und Eisen, August 10, 1922, vol. 42, pp. 1245–1246). In his article describing the cleaning of coal by the flotation method (see p. 296), the author states that he is able to obtain a coal of such a degree of purity that by distillation out of contact with air the residue can be used direct for the manufacture of electrodes ; when graphitised an electrode made from this refined product has a specific resistance of less than half that of an electrode made from ordinary coke.

Steel Works Equipment in Various Countries.—H. B. Allin Smith, *Steel-Making Facilities of Great Britain* (United States Bureau of Foreign and Domestic Commerce: Iron Age, June 1, 1922, vol. 109, p. 1518). A table is given showing the number and size of the electric furnaces in this country. Records show that in 1914 there were about 21 electric furnaces ranging from 1 to 3½ tons per charge. In 1922 there are 148 furnaces with a range of from 5 cwt. to 20 tons capacity.

H. Hoff, *Steelworks and Rolling-Mills of the Arbed Company at Esch* (Stahl und Eisen, July 6, 13, 1922, vol. 42, pp. 1041–1050, 1089–1097). An illustrated account is given of the condition of the iron industry of Lorraine and Luxemburg, as developed by German enterprise up to 1918. The article consists mainly of a description of the works of the Arbed Company at Esch, dealing with the mixer plant, showing the arrangement for heating the mixers with blast-furnace gas, the converter installation, with furnaces fired with coal-tar for melting ferro-manganese, ladle waggon, soaking-pits, cogging mills, shears, bar mill, finishing mills, and wire-rolling mills.

L. J. Barton, *Electric Steel Plant at the Southern Pacific Shops* (Chemical and Metallurgical Engineering, May 3, 1922, vol. 26, pp. 838–840). The steel foundry of the Southern Pacific Railroad Co. at Sacramento, California, is described and illustrated. A 6-ton Heroult basic furnace is in operation for the production of steel castings.

J. D. Knox, *Tinplate Industry's Rapid Rise* (Iron Trade Review, August 31, 1922, vol. 71, pp. 577–581). The author presents statistical data concerning the tinplate industry of America. Tables are given showing the number and capacity of the tinplate mills by companies and by districts. Pennsylvania is the largest producing State.

Basic Slag.—A. Scott and D. N. M'Arthur, *The Constitution of Basic Slag* (Journal of the West of Scotland Iron and Steel Institute, Session 1921–1922, vol. 29, pp. 79–102). The paper contains a summary of previous literature on the subject, a description of the microscopic characters of the slags examined, and a discussion of the constituents and structures in relation to the chemical analyses of the particular slags.

C. F. Juritz, *Basic Slag: The Change in its Composition* (Journal of the Department of Agriculture, July 1922: Chemical News, August 11, 1922, vol. 125, pp. 73–76). The change of composition is due to the fact that in the steel industry the basic Bessemer process has now been superseded by the basic open-hearth process, and the character of the slag has been entirely altered, its phosphorus content having been halved. Before the war the annual output in Britain of high-grade slag with over 15 per cent. of phosphoric oxide was 260,000 tons as against 46,000 tons in 1920. The subject has been given serious attention in England, and the Minister of Agriculture in July 1920 appointed a committee to study the basic slag problem.

A. Demolon, *The Accessory Elements of Dephosphorisation Slags* (Comptes Rendus, 1922, vol. 174, pp. 1703–1706). Experiments were made on a number of slags to determine the amount of calcium soluble in different solvents. The solvents used were distilled water, a 5 per cent. sugar solution before and after calcining the slag, 2 per cent. phenol, a neutral solution of ammonium humate, cold solutions of ammonium chloride of different strengths, a saturated solution of carbon dioxide and mineral acids. In every case the amount of calcium going into solution increased at first very rapidly with the time of shaking, and then only very slowly. The amount of manganese was fairly constant at about 4 to 5 per cent., and was easily soluble in 2 per cent. citric acid.

II.—*CASTING AND TREATMENT OF INGOTS.*

Centrifugal Casting of Steel. *McConway Centrifugally Cast Steel* (Iron and Coal Trades Review, September 8, 1922, vol. 105, p. 355). Illustrated particulars are given of the new McConway process for the production of steel discs by centrifugal and hydraulic methods direct from molten steel (see this Journal, p. 249).

Gases Occluded in Steel.—P. Oberhoffer and E. Piwowarsky, *Determination of Gases in Iron* (Stahl und Eisen, May 25, 1922, vol. 42, pp. 801–806). Experiments were made with the object of estimating the amount of gases occluded in steel, two methods being employed, namely by treatment with bromide and by treatment with sublimate. Both methods gave concordant results in respect of gases containing carbon, but the quantities found were much lower than those obtained by extraction of the gases from the molten metal under vacuum, as the reaction gases are absent. The sublimate method gave too low results for hydrogen, as a portion of this gas is lost in secondary reactions; the bromide method, however, gives trustworthy results for hydrogen. Neither method gave definite indications concerning nitrogen. An investigation of a basic Bessemer and an acid open-hearth steel, before and after deoxidation, showed that the total amount of carbonaceous gases was not greatly altered, but the hydrogen both before and after deoxidation remained absolutely the same.

Ladle Stoppers.—*New Designs of Casting Ladle Stoppers* (Stahl und Eisen, June 1, 1922, vol. 42, pp. 848–850). Various methods for the better attachment of the stopper to the rod are illustrated and described.

FORGING AND ROLLING-MILL PRACTICE.

Forging Practice.—A. Crespin, *Accessories for Soaking-Pits and Reheating Furnaces* (Revue Universelle des Mines, March 15, 1922, vol. 12, Series 6, pp. 512–520). The conclusion of an article, the first portion of which has been recorded in the *Journal of the Iron and Steel Institute*, 1922, No. I. p. 589. Deals with the tongs, charging appliances, and long arms used in charging and withdrawing blooms, ingots, and slabs.

R. J. Weitlaner, *Furnaces Utilise Low Heat Gases* (Iron Trade Review, May 11, 1922, vol. 70, pp. 1332–1334). The utilisation of gases of low heat value in heating furnaces is described. The air for combustion is preheated in regenerators, similar to those used with the open-hearth furnace. One of the latest designs of furnace, which seems to have found favour in Germany, is operated on the regenerative split flame principle.

W. E. Groume-Grjimailo, *Continuous Heating Furnaces for Steel* (Iron Age, August 24, 31, 1922, vol. 110, pp. 465–467, 537–538). The design of continuous heating furnaces is discussed. A roof which drops toward the charging end will result in the concentration of the hottest gases at the front end of the furnace, and is conducive to uniform heating and economy of fuel. A roof which rises toward the charging end will cause the hottest gases to flow toward the charging or rear end of the furnace, where they come in contact with the coldest material. Long furnaces for the uniform heating of shafts, billets, &c., should be given a roof rising toward the end of the furnace at which the waste gas port is situated.

W. P. Chandler, *Heating Furnaces for Blooms, Slabs, and Billets* (Paper read before American Iron and Steel Institute, October 27, 1922). The paper deals with the selection of fuels, types of furnaces, including the non-continuous regenerative furnace, and efficiency tests of such furnaces, the continuous recuperative furnace and efficiency tests, with notes on the design of heating furnaces generally.

H. E. Diller, *Header Machine for Manufacture of Forgings* (Iron Trade Review, September 7, 1922, vol. 71, pp. 643–645). The practice at the plant of the Dayton Engineering Laboratories, Ohio, for the production of small intricate forgings in a header machine is described. The principal advantage of making forgings in this way is stated to be the direction it gives to the grain of the metal. The grain radiates from the centre of the forging.

E. C. Hammond, *Forging Crane Hooks* (Forging and Heat-Treating, June 1922, vol. 8, pp. 272–273). By a method devised at the hammer-shop at the Bement-Niles works at Philadelphia, the time and labour required to forge and finish a hook weighing, say 150 lbs., has been lessened so as to make it an easy matter for a smith and one helper to turn out two perfect hooks in a single morning in two heats instead of in two or three days. The method of operation is illustrated and described.

W. M. Myers, *Merchant Bar made by the Busheled Scrap Process* (Paper read before the American Society for Testing Materials, June 26, 1922, 6 pp.). The paper describes the manufacture of merchant bar iron made from reworked iron scrap or a reworked mixture of iron and steel scrap. The busheling furnaces in which the scrap material is heated are described, and test results are included showing the physical properties and chemical analyses of the material.

Rolling-Mill Equipment and Practice.—*The Hecla and East Hecla Works of Hadfields, Ltd., Sheffield* (Iron and Coal Trades Review, August 11, 1922, vol. 105, pp. 179–182; Iron Trade Review, August 10, 1922, vol. 71, pp. 370–378). An illustrated description is given of the new rolling-mill plant. The total area of the present works is 214 acres. Three very complete electrically driven mills have recently been laid down, including a reversing 28-inch blooming and finishing mill, an 11-inch and a 14-inch bar mill. The furnaces and soaking-pit are of the gas-fired, reversing, regenerative type. The gas is supplied by five producers, each capable of gasifying 10 cwt. of coal per hour. A gravity roller track links the soaking-pit with the continuous furnaces. The 11-inch mill is arranged with five sets of housings, one three-high and four two-high, driven by a 400 to 800 horse-power compound interpole motor having a rated speed of 150 to 250 revolutions per minute. The mill rolls 2½-inch billets to rounds of from 1¼ inch to ½-inch diameter, and squares of from 1¼ to 1 inch. The 14-inch mill is arranged with six sets of housings two-high, driven by a 500 to 1000 horse-power compound interpole motor having a rated speed of 75 to 150 revolutions per minute, the rolls running at the same speeds. This mill rolls 5-inch billets to rounds and squares of from 3 to 1 inch diameter, also to flats from 7 to 1 inch down. The 28-inch mill is capable of rolling down 28 cwt. ingots to 2½-inch billets in one heat. The mill will also roll Hadfield "Era" manganese steel rails up to the heaviest section. The 28-inch mill comprises one cogging and one finishing stand in direct line with the main driving motor, the pinion housing being situated between the motor and the roughing stand. On both sides of the mill are hydraulically operated manipulators of the "Williams" type. The motor has a rating of 3200 with a maximum rating of 11,600 horse-power. The eleven auxiliary motors for driving the live rollers, skids, and screw-down gear on cogging rolls are all of 40 horse-power, running at 500 revolutions per minute.

Universal Mill at the Redcar Works of Messrs. Dorman, Long &

Company, Ltd. (Iron and Coal Trades Review, September 15, 1922, vol. 105, pp. 377–378). An illustrated description is given of this mill, which is of the two-high reversing type, with two vertical rolls on each side of the horizontal rolls. The mill is capable of rolling plates 42 inches wide down to 11 inches. These plates are perfectly square on the edges, and after passing through the flattener and the universal hot straightener are ready for use without any side shearing or machinery, resulting in an average saving in scrap of about 28 per cent. over the ordinary type of mill. When the mill is destined to roll plates the vertical rolls, with the whole of their gear, are lifted together from the side of the mill, which is then capable of rolling plates up to 6 feet wide. When so engaged the slabs are turned by a hydraulically operated pintle in the feed train. The mill is electrically driven, the Ilgner system being employed.

Combined Strip and Hoop Mill of the Whitehead Iron and Steel Company, Ltd. (Iron and Coal Trades Review, September 22, 1922, vol. 105, pp. 417–418). An illustrated description is given of this mill, which is of the Morgan continuous type. The roughening mill consists of a continuous train of seven stands of 12-inch horizontal rolls, and one stand of vertical edging rolls which is placed between the Nos. 5 and 6 horizontal rolls. The train is driven by a graduated series of machine-cut bevel gearing, which regulates the speed of each set of rolls, a reducing unit of double-helical machine cut being placed between the bevel drive and the roughing-mill motor. On emerging from the last stand of roughing rolls the bar is cropped, and then enters the second section of the mill, which consists of one stand of vertical edging rolls, which finally control the width of the finished strip. The finishing mill consists of a train of six stands of 12-inch rolls, which are placed at rather greater centres than the roughing-mill train. On leaving the finishing rolls the hoop or strip is either reeled up in coils or delivered in straight-cut lengths. The roughing mill is driven by a 1500 horse-power 500 volt D.C motor with a speed range of 175 to 400 revolutions per minute, and the finishing mill by a 2500 horse-power motor of similar type

Reconstruction of Ayrton Sheet Mills (Iron and Coal Trades Review, June 30, 1922, vol. 104, pp. 967–969). The lay-out of these new sheet mills at Middlesbrough is described and illustrated. At present there are six 30-inch sheet mills in full commission. The bar and sheet furnaces are gas-fired.

J. D. Knox, *Double Mill Promotes Regularity* (Iron Trade Review, July 20, 1922, vol. 71, pp. 179–181). The author compares the three systems of rolling black plates as practised in America. These are the single mill, four-part system; the single mill, three-part system; and the double mill, three-part system. The development of the mechanical matching and doubling machine reduces the number of heatings given to the steel from four to three. The production is speeded up and the cost minimised.

J. D. Knox, *Only Eleven States Produce Sheets* (Iron Trade Review, August 3, 1922, vol. 71, pp. 303–306). An analysis is given of the American sheet industry, and tables are given showing the number and capacity of sheet mills by companies and by districts. One-half of the output of sheets is produced in the State of Ohio.

Cold-Rolling Strip Mill (Iron Age, May 11, 1922, vol. 109, pp. 1289–1291). The 10-inch mill in operation at the plant of the Greer Steel Co., Dover, Ohio, is described and illustrated. It is a five-stand tandem mill and of a new design. It is electrically driven.

E. D'Amico, *A Modern Rolling-Mill Plant* (Metallurgia Italiana, June 1922, vol. 14, pp. 203–209). An illustrated description is given of the rolling-mill plant of the Terni works, which has undergone reconstruction since the war.

E. D'Amico, *Improvement in Sheet-Mill Practice* (Iron Age, June 15, 1922, vol. 109, pp. 1655–1657). The Boscarelli system of rolling sheets is described and illustrated.

Boscarelli System of Sheet-Rolling (Iron and Coal Trades Review, August 18, 1922, vol. 105, pp. 220–221). The plant installed at the Terni Steelworks for the rolling of sheets on the Boscarelli system is described and illustrated. The bars are charged into a large regenerative furnace by a mechanical charger and skid on water-cooled pipes. They are withdrawn from the furnace by one man and placed on an inclined belt conveyor, from which they are unloaded on to live rollers and carried to the roughing stands. Each train consists of two stands of roughing and two stands of finishing rolls. In front of each stand there is an automatic device for lifting the bars to the level of the rolls. It is provided with a controller which arrests the bars in front of the stands; a stop arrests momentarily the further movement of the bars to the stands, when the lifting device is in motion. When this device is not in operation it is lowered beneath the floor level, and a trap door automatically closes upon it. The use of this feeding apparatus is not necessary to the Boscarelli system, but is an auxiliary for use in the manufacture of heavy sheets. At the roughing stands the sheet bars are rolled down to the thickness suitable for doubling. The sheet packs are then passed through a pair furnace of the muffle type and provided with heat regenerators. An automatic charging device provides a means for reducing the handling of the material. From this furnace the material goes to the finishing stand. Sheets from 0·8 to 3 mm. can be rolled direct from the bar without any reheating operation.

G. C. Brown, *Use of Steam for Cooling Sheet Rolls* (Iron Age, August 3, 1922, vol. 110, pp. 279–280). The best means of using steam for the cooling of rolls is discussed. Steam roughens the surface of the rolls. Especially is this true where the chill is of $\frac{1}{2}$ to $\frac{3}{4}$ inch in depth, and soft or medium in hardness. The author favours the use of deep chilled rolls.

Electrification of the Cordes (Dos Works), Ltd. (Iron and Coal Trades

Review, June 9, 1922, vol. 104, pp. 850–851). An illustrated description is given of the electrical driving equipment of the rolling-mills at this plant.

W. Sykes, *The General Effect of Electrification on the Operation of Steel Mills* (Paper read before the American Iron and Steel Institute, May 26, 1922, 29 pp.). The records of outputs of various types of mills with electric drives are presented, with some discussion of the kind of motor drive for continuous mills and reversing mills that has given the most satisfactory results. The questions of maintenance and repair, cost of distribution, constant and adjustable speed drives, and auxiliary motor equipments are considered.

B. G. Lamme and W. Sykes, *Electrification of Mills* (Paper read before the Association of Iron and Steel Electrical Engineers, September 1922: Iron Trade Review, September 14, 1922, vol. 71, pp. 716–718, 724). The early installations in Europe and America are compared, and types of motors and voltages are discussed. One great impetus to the advancement of electric drive has been the development of adequate and reliable gearing.

R. B. Gerhardt, *Mill Electrification Progress* (Paper read before the Association of Iron and Steel Electrical Engineers, September 1922: Iron Trade Review, September 21, 1922, vol. 71, pp. 783–786). The author outlines recent developments in the electrical driving of rolling-mills, and gives particulars of new installations put down in Europe and America.

W. S. Hall, *The Application of Electric Power in the Iron and Steel Industry* (Association of Iron and Steel Electrical Engineers, 1922, vol. 4, pp. 127–151). The author discusses the various sources of waste heat in steelworks and its conversion into electric power.

G. Fox, *Electric Motor Drive in Steel Industry* (Paper read before the Western Society of Engineers: Iron Age, August 10, 17, 1922, vol. 110, pp. 339–341, 408–412). Rolling-mill requirements as to power, adjustability, and changing of speed, flow of metal under rolling pressure and its effect on power demands, are discussed.

E. F. Entwisle, *The Economic Importance of the Power Plant in the Steel Industry* (Paper read before American Iron and Steel Institute, October 27, 1922). The ratio of the cost of total power generation to the costs of some of the principal items entering into production costs has been calculated, and figures are tabulated showing the importance of power as an item in making up the costs of production in a given works.

E. L. Fletcher, *Power Required to Roll Wrought-Iron Bars* (Iron Age, April 27, 1922, vol. 109, p. 1144). The results of tests are given showing the power required to reduce 3-inch billets to $\frac{3}{4}$-inch rounds.

Hyatt Roller Bearings for Iron and Steel Works Equipment (Iron and Coal Trades Review, June 2, 1922, vol. 104, pp. 814–815). The application of this type of roller bearing to rolling-mills, bogies, and hot-saws is outlined. The hollow spiral rollers in Hyatt bearings act as oil containers and distributors, ensuring positive lubrication over all the bearing surfaces.

A. M. MacCutcheon, *Anti-Friction Bearings in the Steel Mill* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, August 3, 10, 1922, vol. 110, pp. 267–268, 354–355). The application of ball and roller bearings to steel mill motors is discussed. The design of ball and roller bearing mountings is dealt with.

G. Fox, *Electric Brakes for Steel Mills* (Blast-Furnace and Steel Plant, May 1922, vol. 10, pp. 278–282). The common types of brakes in use are the band brake, the disc brake, and the shoe brake. Brakes may also be classified according to their use on direct current or alternating current systems. In general, it is more desirable practice to retard and stop loads by dynamic breaking and to utilise the friction brake largely for holding. The different kinds of brakes are illustrated and described.

W. H. Melaney, *Breakage of Rolls on Sheet and Tin Mills* (Blast-Furnace and Steel Plant, May, July, August, 1922, vol. 10, pp. 284–286, 384–385, 425–427). The causes of breakage and the best methods of avoiding them are discussed.

R. C. Rohrabacher, *An Automatic Hot Billet Scraper* (Iron Age, April 27, 1922, vol. 109, pp. 1126–1128). Illustrated particulars are given of an automatic scraping device installed in a Canadian rolling-mill plant. The scraper is set up between two of the stands of rolls in the series, and another immediately following the last stand of rolls. The scrapers are designed to engage the surfaces of the passing billets at whatever pressure required to remove the surface flaws. Pressure is applied independently to each scraper blade, each machine having four cylinders, two of which operate horizontally and two vertically. The apparatus may be operated under air, steam, or water-pressure, and is so designed that the pressure on each blade is subject to separate control. The blades are made of stellite on account of its abrasion-resisting properties.

The Sleeper Plant of the Ebbw Vale Steel, Iron, and Coal Co., Ltd. (Iron and Coal Trades Review, May 26, 1922, vol. 104, pp. 780–781). The lay-out of this plant for the production of steel sleepers is described and illustrated. The flats, after being cut to the required lengths, are carried by means of a conveyor to a point opposite the furnace-charging doors. This conveyor is placed so that the flats can be pushed on to skids with their length at right angles to the furnace. The skids deliver the flats on to the furnace conveyor, which consists of three chains, the top or carrying edges of the links being shaped so that the flats are carried through the furnace at an angle of about 7° with its bottom. The furnace is 54 feet long and 10½ feet wide inside the chamber. It has ten firegrates, five on each side, and is designed to heat the sleeper bars to a maximum temperature of 900° C. at the rate of 15 tons of bars per hour, with a coal consumption of 1½ cwt. per ton of steel heated. The special feature of the furnace is the "Curran" patent regenerative arch. From the delivery end of the conveyor the flats are passed in series through the forming and punching presses, served by two sets of electrically driven three-throw hydraulic pumps, which are each driven by a 60 h.p. Westinghouse motor and a self-contained hydraulic pressure accumulator. The presses are placed in tandem, the sleeper being formed upon the first and punched upon the second. Each press is operated by a boy and is controlled by the movement of a single lever. Five sleepers are completed within the minute with the plant in normal operation. From the punching press the sleeper is conveyed to the tar bosh, then over a drip tray, and finally to the inspection table.

Hollow Steel Sleepers (Zeitschrift des Vereines Deutscher Ingenieure, September 23, 1922, vol. 66, p. 894). Illustrations show the dimensions of hollow steel sleepers, which are said to have advantages over the channel form of steel sleeper on account of their greater springiness.

Manufacture of Armour Plate and Guns.—E. Ehrensberger, *History of the Manufacture of Armour Plate in Germany* (Stahl und Eisen, August 10, 17, 24, 1922, vol. 42, pp. 1229–1236, 1276–1282, 1320–1330). Following an outline of the development of armour plate manufacture the author gives an account of the manufacture and metallurgical treatment of armour plates illustrated by numerous micrographs.

S. G. Koon, *Naval Gun Factory at Washington* (Iron Age, July 13, 1922, vol. 110, pp. 87–90). The lay-out of this factory is described. Exceptionally massive tools are used for the production of the heaviest naval ordnance.

Seamless Tubes.—*The Manufacture of Seamless Steel Tubes* (Iron and Coal Trades Review, June 9, 1922, vol. 104, p. 849). The Pilger mill process for rolling seamless tubes at the works of the Ebbw Vale Steel, Iron, and Coal Co., is described.

Grinding.—H. W. Wagner, *Grinding of Steel* (Iron Trade Review, August 17, 1922, vol. 71, pp. 444–446). The author gives the results of tests showing the effects of heat, mechanical treatment and chemical composition of iron and steel on grinding wheel action. Low grinding resistance was indicated by the grey, chilled, and malleable irons tested. The grey and chilled irons, because of their brittleness, had little wearing effect upon the wheel, although chilled iron is hard enough to resist rapid penetration under the pressure employed for the test for the removal of material. Some of the results obtained on manganese steel were unexpected in view of the reputed toughness of this material. It appeared that this steel was tough mainly in resisting abrasion under limited pressure encountered in practical service, and it is ground readily without much wheel wear when forced. Alloy steels, as a class, do not develop as much grinding resistance as carbon steels of similar properties, although their values vary widely.

Wire Manufacture.—K. B. Lewis, *Wire Manufacturing in England and France* (Blast-Furnace and Steel Plant, June 1922, vol. 10, pp. 323–325). The author presents a general comparison of the wire-drawing practice of England and France with that of the United States. The methods of manufacture are affected to some extent by the economic and labour conditions.

J. D. Knox, *Wire Rope Industry* (Iron Trade Review, September 14, 1922, vol. 71, pp. 709–715). The author gives an illustrated account of the manufacture of wire and wire ropes at the plant of the Williamsport Wire Rope Co.

Works of the Lancashire Wire Co., Ltd. (Iron and Coal Trades Review, July 7, 1922, vol. 105, pp. 1–3). The lay-out and equipment of the wire-drawing plant at the Trafford Park Works of this company are described and illustrated.

The Works of John and Edwin Wright, Ltd. (Iron and Coal Trades Review, August 18, 1922, vol. 105, pp. 215–216). A brief description is given of the lay-out of the Universe Works, Birmingham. The works are equipped throughout with an unique range of machines for the production of wire rope from the finest strand of cable used in aircraft construction to ropes of over 18 inches in circumference.

Steel Wool.—L. W. Moffett, *Metal Wool and Methods of Making it* (Iron Age, September 7, 1922, vol. 110, pp. 591–592). An illustrated description of the plant and methods for the manufacture of steel wool.

FURTHER TREATMENT OF IRON AND STEEL.

Case-Hardening.—L. Guillet, *Recent Progress in the Practice of Case-Hardening and Tempering* (Génie Civil, September 23, 1922, vol. 81, pp. 273–277). The various factors to be taken into consideration in case-hardening are: the composition of the material to be case-hardened, the temperature of the operation, the period of heating, the agent employed, protection of parts not requiring to be case-hardened, and the subsequent heat treatment. The material generally used is a dead soft steel containing about 0·1 per cent. carbon with 0·3 to 0·4 per cent. manganese, or it may be a steel with about 2 per cent. of nickel with low carbon, or a steel with 6 to 7 per cent. nickel. This latter class of nickel steel is, however, very little used, as the case never becomes finally martensitic but consists of a mixture of martensite and gamma iron of a hardness considerably lower than that of ordinary case-hardened and tempered steel. The chief point of interest about the case-hardening of nickel steels is that such steels do not show brittleness after simple quenching, but nickel steels in general do not acquire so high a degree of surface hardness as carbon steels, though this disadvantage can be obviated by the addition of a small quantity of chromium not exceeding 0·5 per cent. With regard to the temperature, formerly it was common practice to case-harden at about 1000° C. and sometimes at 1050°. The common practice now is not to exceed 950°. At that temperature, using a case-hardening mixture of 60 per cent. charcoal and 40 per cent. barium carbonate, the rate of penetration is at about 0·1 mm. per hour. As a protection for parts not requiring to be case-hardened the following coatings have been tried: copper electrolytically deposited, copper deposited by the Schoop process, nickel electrolytically deposited, and tin. Of these the electrolytic coating of copper has proved the most satisfactory.

J. Galibourg and M. Ballay, *Protection against Case-Hardening by the Direct Application of a Painted-on Layer* (Revue de Métallurgie, Mémoires, April 1922, vol. 19, pp. 222–226). Various methods for the protection of parts not requiring to be case-hardened when case-hardening operations are required for adjacent parts, are reviewed. Preference is given to a paint made from two parts by weight of powdered copper, one part of emery, and sufficient sodium silicate solution to work up into a thick paint. It is said to adhere well during heating and to shell off readily after case-hardening and quenching. The parts to which it is applied must be thoroughly cleaned from both animal and vegetable grease, and the paint is to be applied in a rather thick layer. Protective coatings resulting from copper deposition, either direct from solutions or deposited electrolytically, are likewise discussed. There is not much to be said in their favour, and they take a good deal of time to form. Even then they require protection by the application of a paint of the nature described above.

W. P. Wood and O. W. McMullan, *Selective Case-Carburising* (Chemical and Metallurgical Engineering, June 7, 1922, vol. 26, pp. 1077–1080). A review of the various methods of producing local case-hardening. An electrolytically deposited plate of copper furnishes the most satisfactory metallic coating. Non-metallic coatings have not heretofore proved generally successful under all conditions, and experimental work with various mixtures which have been recommended has shown that they are not uniformly successful. A non-metallic coating consisting of definite mixtures of sodium silicate with either finely ground asbestos or alumina furnishes good protection from carburising conditions. It is easily painted on the metal and may be removed by immersion in molten sodium hydroxide or by quenchings in water. Calcium chloride in the molten state is also useful in loosening these coatings.

R. A. Millholland, *Problems in Localised Case-Hardening* (Iron Age, August 3, 1922, vol. 110, pp. 265–266).

H. B. Knowlton, *Carburising and Decarburising in Case-Hardening* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1155–1166). Successful case-hardening must produce cases of the proper depth, percentage of carbon, and free from decarburisation. The temperature of the lining of the furnace and the ratio of the weight of the charge to the weight of the lining are important factors determining the speed of heating. The use of test-pins for determining the depth of case before removing the charge from the furnace is recommended Carburisation with solid materials is largely due to the action of carbon monoxide. The concentration of carbon in the case increases with the amount of carbon monoxide. Carbon dioxide either inhibits carburisation or causes decarburisation. Reheating in the open furnace, if properly done, should not cause excessive decarburisation.

A. H. d'Arcambal, *Case-Hardening* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1111–1124). The author has made a study of the chemical reactions taking place in the cyanide process of case-hardening, and gives the results of Izod notched bar tests on several types of case-hardening steels. Hardness obtained on cyanide hardened parts is due both to the absorbed carbon and nitrogen, principally to the latter. The higher the temperature (up to 1550° F.), and the longer the time of immersion, the greater percentage of these two elements was found. The combined nitrogen in the areas of highest nitrogen concentration appeared as pearlite patches and in the less concentrated sections as needles. With regard to the Izod notched bar tests, conducted on plain carbon and alloy case-hardening steels, all the alloy steels showed lower impact readings after carburising and single quenching for case refinement only, than was found on the specimens double treated after carburising. The core fractures on single treated specimens also showed a coarse-grained structure, as compared with the fine-grained fractures on the double treated specimens.

Case-Hardening by Cyanide (Iron and Coal Trades Review, July 21, 1922, vol. 105, p. 83). The use of sodium cyanide for case-hardening is briefly dealt with. Where a case of not more than $\frac{1}{32}$ inch is sufficient the parts may be conveniently and economically case-hardened by this method.

S. C. Spalding, *A Comparison of the Rate of Penetration of Carbon into various Commercial Steels in Use for Case-Carburising* (Transactions of the American Society for Steel Treating, August 1922, vol. 2, pp. 950–976). The types of steels investigated comprised plain carbon, cold rolled, chrome-silico-manganese, chrome-vanadium, 3½ per cent. nickel, 5 per cent. nickel, two types of chrome-nickel, and a chrome-molybdenum steel. Test-bars were heated for periods varying from five to fifty-five hours and cooled in pots. The depth of case was measured by the microscope. Time penetration curves for each temperature and each type of steel are given, with a combined sheet showing all steels plotted to the same co-ordinates for one temperature. Complete series of photomicrographs of all steels at different times and temperatures are given with explanatory discussion. The results indicate the superiority of the chrome-nickel and chrome-molybdenum steels in so far as rate of penetration of carbon is concerned. The chrome-vanadium and chrome-silico-manganese steels come next, then the straight carbon steels, with the nickel steels last. The difference between the cold-rolled and hot-rolled straight carbon steels shows the retarding effects of high phosphorus and sulphur. From the standpoint of microstructure the results indicate the superiority of the alloy steels over the straight carbon steels.

H. W. McQuaid and E. W. Ehn, *Effect of Quality of Steel on Case-Carburising Results* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, vol. 67, pp. 341–391). It is contended that the presence of excess of dissolved oxides in the steel, as made in the melting furnace, affects permanently the results obtained in carburising and hardening, and that it is possible that the presence of dissolved oxide can result in total unfitness of low-carbon steel for case-hardening purposes.

E. W. Ehn, *Irregularities in Case-Hardened Work caused by Improperly made Steel* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1177–1202). See also this Journal, 1922, No. I. p. 157.

T. G. Selleck, *The Carbonising Process—Relation of Time and Temperature to Depth of Case* (Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 705–709).

Annealing Furnaces.—A. D. Dauch, *Regenerative Car Furnace* (Iron Age, May 4, 1922, vol. 109, pp. 1217–1218). Illustrated particulars are given of a large regenerative car-type electric furnace for annealing wire. It consists of three chambers, heating and cooling chambers set in tandem with a common door between, and a preheating chamber placed alongside the cooling chamber, with a full side opening between to allow free interchange of heat from the hot to the cold charge. Electric heating units are installed in the heating chamber only.

Equipment for Annealing Wire (Iron Trade Review, June 29, 1922, vol. 70, pp. 1875–1876). A new design of annealing furnace, fitted with a carriage for the annealing pots, has been developed by M. B. Kelly, and a description is given.

C. L. Ipsen, *The Electric Furnace as it affects Over-all Costs of Heat-Treated Parts* (Transactions of the American Society for Steel Treating, August 1922, vol. 2, pp. 984–989). In the development of steel treating furnaces each change in the form of fuel has been to a higher priced fuel, indicating that there are factors more important than fuel costs. A table is given showing the over-all cost of several heat-treated parts and the percentage of this cost that is chargeable to fuel. Electricity is the ideal heat source for steel treating, because (1) the temperature of heat source is only slightly higher than the parts being treated, so that no part can be overheated ; (2) absolute temperature uniformity can be maintained ; (3) the human element is reduced by the use of accurate and reliable temperature control. In the selection of any furnace first consideration should be given to cost and quality of finished parts, as it will, in most cases, show that the highest-priced heat source is the least expensive.

P. J. Myall and L. A. Mekler, *Continuous Furnaces and their Applications* (Forging and Heat-Treating, July 1922, vol. 8, pp. 322–326). A classification of continuous furnaces is presented and types of furnaces are recommended for various operations, such as heating for fabrication, heat-treating, carbonising, and malleableising.

F. C. Langenberg, *Planning and Routing of Forging and Heat-Treatment Work at Watertown Arsenal* (Transactions of the American Society for Steel Treating, June 1922, vol. 2, pp. 763–768). The routine work and system of control in the forging and heat-treatment shops of the Watertown Arsenal are outlined.

W. J. Merten, *A Coiling and Heat-Treating Plant for Helical Springs* (Transactions of the American Society for Steel Treating, August 1922, vol. 2, pp. 977–983). The author points out the importance and necessity for utilising adequate coiling and heat-treating processes if a high standard in spring performance is to be attained. The lay-out of a plant in which the spring materials are constantly under control is discussed in detail.

Methods of Handling and Heat-Treating Springs (Canadian Machinery, February 23, 1922, vol. 27, pp. 21–25). Describes furnaces of the stationary and continuous types for the heat treatment of springs, and the practice to be followed for securing uniform heating and cooling.

E. F. Lake, *Modern Methods of Making Leaf Springs* (Iron Age, May 11, 18, 1922, vol. 109, pp. 1269–1274, 1343–1346). The equipment and the continuous process employed by the American Autoparts Co., of Detroit, for the manufacture of leaf-springs is described and illustrated.

R. B. Schenck, *Heat-Treating in Lead* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1203–1212). While molten lead is far from being an ideal heating medium, in comparison with the salts in commercial use as bath materials, it has the advantage of a much wider range of working temperature and a much higher heat conductivity. These two properties permit the use of lead in units of very large capacity for temperatures of 650° to 1700° F., thus covering the hardening and tempering ranges of nearly all commercial steels. The selection of pot materials, the design of the pots and brickwork, and the methods of firing and operating, are discussed. Comparing the lead pot with the oven furnace from the standpoint of operating cost, for hardening, the oven furnace is the cheaper of the two, and for tempering the costs are slightly in favour of the lead pot. The greatest argument for the lead pot furnace is the high quality of the treated product resulting from uniform and accurate temperatures.

G. C. McCormick, *Furnace Atmospheres and their Relation to the Formation of Scale* (Transactions of the American Society for Steel Treating, August 1922, vol. 2, pp. 1006–1012). The author has investigated the phenomena of scaling in oxidising, neutral, and reducing atmospheres during the heat treatment of steel. The scale which was formed on low, medium, and high carbon steels when heated to various temperatures and under varying conditions of furnace atmospheres, has been determined quantitatively. Under certain conditions, oxidising, neutral, and reducing atmospheres permit of the formation of scale.

S. Pagliani, *On the Determination of Heat Losses in Gas-Fired Reheating Furnaces* (Giornale di Chimica Industriale ed Applicata, September 1922, vol. 4, pp. 391–392). The heat lost by radiation and by other means is ultimately a function of the carbon available in the fuel, and in the case of gases, of the percentage of carbon oxides present. Formulæ, culled from a number of sources, are quoted in support of this contention, and serve as a basis for the estimation of the percentage heat losses which may be expected to occur in practice in reheating and in annealing furnaces.

Pyrometry.—H. C. Knerr, *Accuracy in Temperature Measurements* (Forging and Heat-Treating, May 1922, vol. 8, pp. 235–237). It is necessary to make allowance in heating steel to the proper quenching temperature for the variations in the composition of steels, since a variation of 0·1 per cent. of the carbon content would alter the upper critical point by about 35° C.; slight changes in nickel or manganese would also affect the critical point in the same way. The potentiometer class of pyrometer is recommended as preferable to the millivolt system on account of its greater dependability.

J. A. Succop, *Importance of the Proper Heating and Cooling of Steel* (Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 673–679). The author discusses the importance of time, temperature, surface, and mass in the heating and cooling of steel. He concludes that a uniformly heated furnace is not the only factor in producing a uniformly heated product. The material cannot be heat-treated satisfactorily when the reading of the pyrometer is the only guide. Correct thermal expansion and contraction can be secured only through proper loading, charging at a low temperature, and by slow firing. The human element also plays an important part in the proper heating and cooling of steel.

Heat Treatment of Material.—E. J. Janitzky, *Relation of Time for Heating Round Sections to Surface per Pound of Steel Exposed* (Forging and Heat-Treating, April 1922, vol. 8, pp. 179–181). Reference is made to the paper by M. E. Leeds, published 1915 by the American Society for Testing Materials, dealing with some neglected phenomena in the heat treatment of steel. Experiments were made with the object of finding the mathematical relation between the surface per pound of steel, and the time required to heat a given section to a definite temperature. The following general formula has been derived for computing the time to heat round bars of different diameters:

$$T \times S = C + L,$$

in which T is the time required to heat the steel to the temperature of the furnace, S is the surface in square inches per pound of steel for the particular section, C is a constant found to be 5·3 for round steel bars, and L is the lag in hours, which is constant for each temperature but varies with different temperatures, the time lag for each temperature in the experiment having been found to be:

Temperature in Deg. Fahr.	Time Lag in Hours.
1600	0·15
1200	1·00
1000	1·4
1400	1·85

Thus for specimens heated to 1600° F.

$$T = \frac{5 \cdot 3}{S} + 0 \cdot 15.$$

The actual times have been found by trial to agree very closely with the calculated times.

W. E. McGahey, *Heat Treatment of Large Forgings by Oil, Gas, and Electricity* (Transactions of the American Society for Steel Treating, June 1922, vol. 2, pp. 799–801). The author deals with the value of uniformity in heating, which is largely dependent on temperature control and the defects that may result from non-uniformity. The conditions governing temperature control and the difference in method of control for oil, gas, and electric furnaces are also discussed.

W. B. Crowe, *Factors influencing Mass Heat Treatment* (Transactions of the American Society for Steel Treating, July 1922, vol. 2, pp. 869–875). The author points out some of the contributory causes of failure which should not be chargeable to poor heat treating, and discusses some of the points in the heat treatment of large masses. Complete saturation is one of the most essential requisites towards good heat-treating. A good empirical rule that has been found to be quite satisfactory, where the mass has a length and width several times that of the thickness, is to allow one hour per inch of thickness for heating to the desired temperature and two-thirds of an hour per inch for saturation.

E. J. Janitzky, *Influence of Mass in Heat Treatment* (Iron Age, September 28, 1922, vol. 110, pp. 788–790). The author has studied the effect of nickel, chromium, and their combinations on the influence of mass in heat treatment.

H. Brearley, *The Making, Forging, and Heat-Treating of Nickel-Chromium Steels* (Paper read before the Association of Drop Forgers and Stampers in Birmingham: Forging and Heat-Treating, August 1922, vol. 8, pp. 341–345). The author discusses in detail the characteristics and nature of nickel-chromium steels, and shows the causes of failure and the remedy. A comparison of the strength properties of nickel and nickel-chromium steels is given.

H. C. Loudenbeck, *Steel for Crankshafts: Its Heat Treatment* (Forging and Heat-Treating, April 1922, vol. 8, pp. 181–183). Notes are given on the heat treatment required to secure best results from crankshafts of carbon steel, case-hardened carbon steel, and alloy steels.

L. Aitchison and G. R. Woodvine, *The Changes of Volume of Steels during Heat Treatment. 1. Air Hardening Nickel-Chromium Steels.* (This Journal, p. 175.)

H. Rowsing and J. Sissener, *Variation of Hardness in Chrome Steel, according to Heat Treatment* (Jernkontorets Annaler, 1922, vol. 77, pp. 382–386).

I. H. Cowdrey, *The Efficacy of Annealing Overstrained Steel* (Transactions of the American Society for Steel Treating, June 1922, vol. 2, pp. 802–808). Overstrain of metal, when its temperature is below the transformation range, renders the steel harder, more brittle, and less resistant to shock. Proper annealing suffices completely to restore the normal properties of low carbon steel even after the most severe overstrain.

C. T. Hewitt, *Ball-Bearing Steel and its Heat Treatment* (Forging and Heat-Treating, April 1922, vol. 8, pp. 196–198). Steels containing 0·60 to 1·50 per cent. of chromium used for ball-bearings are required to meet extremely severe service conditions. The methods of annealing and hardening are described.

H. Styri, *Heat Treatment of Chrome Steel for Ball-Bearings* (Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 718–729). Highest grade steel for ball-bearings contains about 1 per cent. of carbon and 1·4 per cent. of chromium. The proper conditions for hardening this steel are discussed, and the phenomena generally accompanying hardening are described. Special consideration is given to the effect of varying the rate of cooling. The paper is accompanied by numerous photomicrographs.

H. G. Freeland, *Ball Steel* (Transactions of the American Society for Steel Treating, July 1922, vol. 2, pp. 898–917). The author discusses at length some of the problems in the manufacture of ball-bearings, and shows how the ball-forming operations tend to accentuate certain defects in the material used. The material used is an electric furnace chrome carbon steel. The carbon range is between 0·95 to 1·05 per cent., while the chromium content increases with the ball size, from 0·75 per cent. for ball between $\frac{1}{8}$ and $\frac{5}{8}$ inch to 1·35 to 1·65 per cent. for balls above $1\frac{3}{16}$ inch. The chief types of defects in ball steel which cause the greatest trouble in the production of steel balls are seams and decarburisation.

Welding and Stamping.—F. N. Speller, *Steel for Forge Welding* (Mechanical Engineering, July 1922, vol. 44, pp. 443–444). The principal factors affecting the welding quality of steel are discussed. The ease with which wrought iron is welded is probably due to the presence of about $1\frac{1}{2}$ per cent. of easily fusible cinder which enables the metal to be welded at a comparatively low temperature and protects it from oxidation at high temperature. Soft welding steel may be made by the Bessemer or open-hearth process, but should be made especially for the purpose of welding, that is, it should have sufficient of the characteristics of wrought iron readily to form a welding scale at the lowest possible temperature. Highly refined steels, ingot iron, or electric steel are as a rule lacking in this respect, and do not show as good a welding quality as soft welding steel or wrought iron. Comparatively small quantities of nickel, chromium, and silicon interfere seriously with welding, and each of these elements should be under 0·05 per cent. Carbon should certainly be under 0·30 per cent. for any kind of forge welding. The higher the carbon the lower the melting point and burning point of the steel, the burning point being the temperature at which the grain growth has increased to such a degree as to cause disintegration and intergranular oxidation of the metal. Sulphur up to 0·05 per cent. is not harmful, and phosphorus up to 0·04 is beneficial to welding. The manufacture and composition of the steel have much to do with the formation of a suitable welding scale. The range of temperature between the melting point of the scale and the burning point of the metal is about 56° C. in good welding steel, and it is this self-fluxing quality which makes possible the welding of steel on a large scale without artificial fluxes. The usual temperature at which soft steel will weld satisfactorily is from 1370° to 1420° C. Eighty tests of forge welds were made on two rings cut from the ends of hammer-welded pipes of $\frac{1}{2}$-inch material, and the results are compared with the original material from the same pipes. The average transverse tensile strength was 23·5 tons per square inch in the original material, and the average of all tests gave the efficiency of weld as 92·7 per cent., the average at the extreme end of the pipe being 90·3, and at 2 inches from the end 95 per cent. The conditions for specifications of steel for forge welding are stated.

L. J. Steele and H. Martin, *The Cyc-Arc Process of Electric Welding* (Journal of the Institution of Electrical Engineers, 1921–22, vol. 60, pp. 136–157). The authors describe their electric arc-welding machine designed for welding brass studs on to steel plates. Perfect welds can be obtained, and the advantages claimed are that the weld is of great strength due to the interpenetration of the metal, combined with an extremely local heating effect and the avoidance of oxidation. The structure is not weakened by drilling; the watertightness of bulkheads is not impaired, and the studs can be fixed with great economy in time and labour. The pressure of current need not exceed 60 volts, and the amount of energy required to weld a $\frac{1}{2}$-inch stud to a plate is not more than $\frac{1}{80}$ kilowatt-hour.

O. H. Eschholz, *Phenomena of Arc Welding* (Transactions of the American Electrochemical Society, 1921, vol. 39, pp. 265–277). A detailed discussion of metal deposition, fusion, and arc stability during electric welding, including the function of transport of metal by molecular forces, the effect of the evolution of gases, and vaporisation and condensation. It is concluded that molecular forces play the main part. Under fusion are considered the effects of the impact of ions, atmospheric convection currents, sudden liberation of gases, and the combination of the material with oxygen and nitrogen. Arc stability is regarded in relation to long and short arcs, constant potential circuits, and use of ballast resistance.

O. H. Eschholz, *Properties of Arc Deposited Steel* (Iron Age, June 29, 1922, vol. 109, pp. 1803–1805). Some of the more important characteristics of arc-fused metal are considered. The tensile properties of a number of specimens are given, and the changes produced in cast arc metal by hammer forging are also shown.

H. Neese, *Electric Arc Welding of Mild Steel and Cast Iron* (Stahl und Eisen, June 29, August 3, 1922, vol. 42, pp. 1001–1013, 1192–1198). The results of experiments are fully described, as carried out with a view to determining the most suitable conditions as regards strength of current and electrodes to be employed for the welding of mild steel and cast iron parts. Impact and tensile tests were made on welded mild steel pieces for the purpose of determining the average strength of the weld compared with that of the original material. The electric welding of grey cast iron parts, using soft steel wires as electrodes, and without preheating the casting to be welded, could not be satisfactorily effected. Cracks invariably occurred and blowholes formed in the weld. By heating the parts to be welded and using cast iron electrodes, and reheating and cooling slowly after welding, a good sound weld can be obtained.

E. S. Humphrys, jun., *The Arc Welding of Structural Steel* (Iron Age, May 25, 1922, vol. 109, pp. 1422–1425). The author describes a number of tests made to determine the approximate strengths of different types of welds.

T. Spooner and I. F. Kinnard, *Electrical and Magnetic Weld Testing* (Paper read before the American Society for Testing Materials, June 1922: Iron Age, July 20, 1922, vol. 110, pp. 139–141). The paper describes some preliminary tests to determine the possibility of applying electrical and magnetic methods for testing the quality of butt welds joining steel plates. It seems that the magnetic methods give the more consistent results. For butt-welding it is quite feasible to state definitely from the magnetic test whether the weld is good when the results are properly interpreted. While the electrical or magnetic tests do not detect small isolated bad spots with certainty, a fairly poor weld extending over considerable distance will be indicated without the slightest possibility of doubt. It is apparent that the tension tests indicate much poorer quality of welds than the magnetic or electrical methods. However, it is believed that the tension tests indicate a poorer quality than actually exists, while the electrical and magnetic tests show more nearly the average quality.

C. Diegel, *Electric and Flame Welding: The Use of Covered Wire Electrodes* (Stahl und Eisen, August 24, 1922, vol. 42, pp. 1309–1315). On comparing the strength of welds made by electric methods with that of oxy-acetylene welds, the flame-welded material proved to be tougher than the electrically welded. A covering material commonly in use for the wire electrodes which supply the material for filling the weld, was found to affect the quality of the flame weld injuriously, when used to cover wires for filling such welds.

A. T. Wall, *Electric Welding applied to Steel Construction, with Special Reference to Ships* (Proceedings of the Institution of Mechanical Engineers, 1922, vol. 1, pp. 239–288; Engineering, February 24, 1922, vol. 113, pp. 241–244). The paper calls attention to the various ways in which electric welding is being applied to ship construction, and indicates further possibilities in this connection for steel structures. The application of electric welding to the structure of a ship or any other steel structure would result in increased efficiency on account of the saving in material and better jointing. The cost need not be greater than riveting. In the case of ships the upkeep cost would be reduced. Details of electrically welded hulls of ships are shown.

J. L. Anderson, *Automatic Seam Welding and the Manufacture of Tubes* (Acetylene Journal, April 1922, vol. 23, pp. 483–489). A process of manufacturing welded tubing is described which it is claimed makes possible the production of thin-walled tubing at a fraction of the cost of seamless steel tubing.

D. Richardson, *Hyde Welding Process* (Welding Engineer, March 1922, vol. 7, pp. 32–34). The method consists in uniting two pieces of iron or steel by a process involving both welding and brazing. The surfaces are joined by means of molten copper, the copper impregnating the mass of metal.

G. O. Carter, *Cutting and Welding of Castings* (Paper read before the American Foundrymen's Association, June 1922: Iron Trade Review, July 13, 1922, vol. 71, pp. 107–110). Some of the important points to be observed in the welding and cutting of castings are discussed. In order that operators can work with the minimum interruption caused by changing of tips and altering of pressures castings should be classified according to the size of the risers.

N. T. Thurston, *Steps in Stamping a Draw-Bolt Tube* (Iron Age, August 17, 1922, vol. 110, pp. 401–403). The operations involved in the stamping of draw-bolt tubes are outlined.

Manufacture of Cutlery.—H. R. Simonds, *Making Cutlery in New England* (Iron Trade Review, July 13, 1922, vol. 71, pp. 111–116). The methods of making cutlery in New England is described and illustrated. Manual operations predominate in the manufacture of high-grade cutlery although automatic machines are used to perform many operations.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties of Cast Iron.—E. Schüz, *Experiments for the Determination of the Critical Temperature in the Annealing of Grey Castings* (Stahl und Eisen, September 28, 1922, vol. 42, pp. 1484–1488). The hardness of grey cast iron depends on the amount of combined carbon ; metallographically speaking, the hardness producing constituents are those containing combined carbon, such as cementite, ledeburite, the binary and ternary phosphide eutectic and pearlite, the softest constituents being ferrite and graphite. Pearlitic cast iron, in which the combined carbon does not exceed 0·9 per cent., contains, however, no free cementite and a negligible amount of ledeburite, consequently the hardness is due almost entirely to the presence of pearlite. Neither the phosphide eutectic nor the graphite have much influence on the state of hardness. The hardness of pearlitic cast iron of eutectoid composition varies from 170 to 220 on the Brinell scale, according to the grain size, which is dependent on the rate of cooling. The more the combined carbon percentage is reduced, the more ferrite separates out and the softer the metal becomes. Pure ferritic cast iron has a Brinell hardness of 90 to 110. For the purposes of heat economy, as well as of obtaining the desired degree of hardness, it is important to know the point at which the carbide will dissociate to form ferrite and temper carbon, and with this object experiments were made on castings having the following composition :

Total carbon	3·56	Manganese	0·56
Graphite	3·06	Phosphorus	0·38
Combined carbon	0·50	Sulphur	0·112
Silicon	2·26		

The hardness was 160 to 164 Brinell units, and the specimens, measuring 15 × 20 × 25 millimetres, were cut from a turned cast iron ring of 220 millimetres diameter and 17 millimetres thickness of wall. The annealing was performed in an electric tube furnace with automatic temperature control. The results of annealing at different temperatures for different periods of time showed that the separation of pearlite into ferrite and temper carbon begins after twenty-four hours' heating at 500° C., after six hours at 550°, and after three hours at 575°. The separation is complete after twenty-four hours' annealing at 600° and after three to six hours at 650°. If the annealing process is performed in such a manner that the separation of pearlite in ferrite and temper carbon is only partially or locally completed and has not proceeded uniformly throughout the piece, the properties of the casting are very injuriously affected.

E. Schüz, *The Frequent Appearance of the Ferrite-Graphite Eutectic in Cast Irons* (Stahl und Eisen, August 31, 1922, vol. 42, pp. 1345–1346). The occurrence of the ferrite-graphite eutectic has often been noticed in small grey iron castings cast in sand moulds without any further heat treatment. The arrangement of the eutectic in the structure of the metal is illustrated by means of several micrographs. The tendency for the eutectic to form would appear to depend entirely on the chemical composition of the metal, and in view of the fact that a cast iron with much graphite eutectic has good mechanical properties and is easy to machine, it would be of great practical interest to discover some means of artificially producing the eutectic. Experiments with this object are in progress.

E. Piwowarsky, *The Soft Annealing of Grey Castings* (Stahl und Eisen, September 28, 1922, vol. 42, pp. 1481–1483). By a suitable heat treatment out of contact with air grey castings, of which the strength properties are of less importance than capability of rapid and cheap machining, can be made so soft as to permit of a cutting speed of 180 metres per minute. In the temperature range between Ar1 and Ac1, if the silicon content of the iron be sufficiently high, the dissociation of the pearlite proceeds rapidly enough to enable the desired result to be attained within a reasonable time. But the best method to secure complete soft annealing is to heat the casting rapidly to slightly above Ac1, followed by cooling so controlled that the cooling rate throughout the Ar1 interval does not exceed 1° to 2° C. per minute.

J. W. Bolton, *Influence of Graphite on Iron* (Foundry, June 1, 1922, vol. 50, pp. 436–443). The author discusses the formation of graphite in cast iron and semi-steel and its influence on the physical properties of grey iron.

T. Kikuta, *On the Growth of Grey Cast Iron during repeated Heatings and Coolings* (Science Reports of the Tohoku Imperial University, Sendai, April 1922, vol. 11, pp. 1–17). Experiments were conducted to investigate the leakage of air through the wall of grey cast iron at high temperatures. The test was carried out with a hollow cylinder. The results show the leakage rate of air increases up to sixty heatings, and then decreases as the number of heatings increases. Below twenty heatings the leakage rate is almost constant up to 900°, while above thirty-four heatings the rate at first decreases and afterwards slightly increases. From these results it is improbable that the growth of grey cast iron during repeated heating and cooling through the A1 range is caused by the pressure of occluded gases, in the manner as conceived by Okochi and Sato. The growth during the first heating through 700° to 800° is partly attributable to the decomposition of cementite. The continuous growth of grey cast iron in a vacuum during repeated heating and cooling through the A1 range is the effect of the differential expansion at different microportions of the same specimen, numerous fissures or cavities being thus formed in the region of graphite flakes. In an oxidising atmosphere the growth is accelerated by oxides formed and filling the fissures during the Ar1 transformation. Thus the effect of oxidation on the growth is indirect. The growth of white cast iron is almost completed in the first heating to 800°. About one-third of the whole expansion is due to the decomposition of eutectic and pearlitic cementites, and the other two-thirds to the minute fissures formed by the irreversible expansion at different microportions of the same specimen. The elongation observable at a higher temperature than the A1 point is due to the pressure of occluded gases. From the results of the present investigation the author concludes that the oxidation theory put forward by Rugan and Carpenter seems to be untenable.

P. Oberhoffer and W. Poensgen, *Influence of the Cross-Section of the Test-Bar on the Tensile and Transverse Strength of Cast Iron* (Stahl und Eisen, August 3, 1922, vol. 42, pp. 1189–1192). According to Voigt (Annalen der Physik, 1889, p. 573), a material possesses approximate isotropy (quasi-isotropy), that is, its mechanical properties are equal in every direction, and those of the individual crystal are not manifest, when the individual is very minute in proportion to the cross-section of the test-piece and the number of individuals is correspondingly very great. Investigators of the properties of cast iron have shown that the transverse strength of cast iron diminishes as the cross-section is increased, and for their tests have used bars, the thickness, size, and the number of graphite flakes in which were varied, on the ground that test-bars of different sections were sand-moulded, and therefore solidified under different conditions. There arises, however, a condition which has hitherto been little regarded, namely, that the phosphide eutectic, almost always present with graphite in commercial cast irons, exercises a considerable influence upon the tensile properties, seeing that this extremely brittle eutectic is distributed in cellular form throughout the metal, and the size of the cells undoubtedly depends very largely upon the speed of solidification. In using sand-moulded bars, therefore, this is certainly a factor which must be reckoned with; in fact, in addition to varying the size of the bar, three other variables come into play, namely, the graphite content, the size and number of the graphite flakes and the size of the phosphide network. To eliminate these differences, a large mass 600 × 600 × 800 millimetres was cast, having a total weight of 2400 kilogrammes. After slowly cooling, a disc 60 millimetres diameter was cut out, from which absolutely homogeneous bending bars and tensile bars were machined. The results of tests show that the tensile strength per square millimetre rises from 5 kg./mm.^{2} in a 5 millimetre round bar, to about 13·75 kg./mm.^{2} in a 20-millimetre round bar, remaining about constant for bars of larger diameter. The transverse strength rose from 26 kg./mm.^{2} in a 10-millimetre round bar to 30 kg./mm.^{2} in a 20-millimetre round bar, remaining constant in bars above that size.

A. Portevin, *Microstructure of Steely Pig Iron* (Revue de Métallurgie, Mémoires, April 1922, vol. 19, pp. 227–237). Formulæ and a diagram are given relating to the iron-carbon system of steely pig iron. The samples examined contained under 0·15 per cent. of sulphur + phosphorus and may therefore be regarded as pure. In the annealed pig irons the mechanical properties were improved, although ferrite always predominated, arising from the decomposition of the cementite during annealing. The microstructure of pig iron, although complicated by the presence of foreign elements, and for this reason often neglected, can furnish valuable indications relative to the mechanical properties and usefully supplements chemical analysis, which often fails to explain the cause of differences in mechanical behaviour.

A. Portevin, *The Mechanical and Elastic Characteristics of Cast Irons and the Use of the Brinell Test* (Revue de Métallurgie, Mémoires, December 1921, vol, 18. pp. 761–779). The results of tensile tests on cast iron are so variable that this method of testing is practically useless. Experiments with semi-steel castings have led to the establishment of a relationship between maximum stress in tension and the Brinell hardness number.

A. Portevin, *General Considerations Relating to Mechanical Tests for Cast Iron* (Paper presented at the Foundry Congress at Liége: Revue Universelle des Mines, March 15, 1922, vol. 12, Series 6, pp. 507–511). In selecting methods for testing cast iron three main considerations need to be borne in mind: (1) That, with a given molten metal the mechanical properties are essentially related to the rate of cooling and hence depend on the dimensions and nature of the mould, being liable therefore to differ in different parts of the same casting. (2) Elongation on fracture is very low (less than 1 per cent.), hence any deformation to which the metal is subsequently subjected, or any local flaw, will lead to premature fracture. Finally, (3) No matter what mode is adopted for inducing fracture, cast iron has but one manner of fracturing, intergranular fracture, in contradistinction with steel, which in some circumstances may break in two alternative ways. This being so, tests should be carried out either on the casting itself, or on bars cut from it, or from an identical casting run under identical conditions. All results derived from test-bars of different shapes and dimensions cast separately are misleading and bear no necessary relation to the casting itself. A further requirement is to avoid all incidental bending stresses during testing. This necessitates precautions which are too delicate and difficult to ensure in ordinary practice, as in the testing machines employed it is almost impossible to confine the bending stresses entirely in the direction of the axis of the test-piece. As cast iron has but one mode of fracturing, there is no essential difference between the result of static and of dynamic methods of testing. Both tensile and shock tests are therefore misleading if conducted on separately cast test-bars. The methods advocated in view of all these considerations is the Frémont bend test (or, where the length of the test-piece is too short, a shearing test), and a ball hardness test from which, by the use of empirical formulæ, the tensile and compressional strengths of a cast iron bar may be derived. The conclusions arrived at conflict with many views previously held, but the result of countless tests conducted by recognised methods has shown the latter to be devoid of any real or practical signification.

A. Campion and J. W. Donaldson, *Some Influences of Low Temperature on the Strength and Properties of Cast Iron* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, July 13, 1922, vol. 26, pp. 32–36). The authors give the results of tests made on irons of different qualities and composition to determine: (1) Change of volume after repeated heating and cooling to and from 450° and 550° C. (2) Tensile strength after annealing for constant time at temperatures between atmospheric and 700° C. (3) Tensile strength at temperatures between atmospheric and 500° C.

E. V. Ronceray, *New Methods of Testing Cast Iron* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, July 6, 1922, vol. 26, pp. 5–12). The author reviews at length the experiments of Frémont and Portevin on the testing of cast iron.

High-Test Iron Castings (Iron Age, July 20, 1922, vol. 110, pp. 149–150). Particulars are given of the new tentative specifications for high-test grey iron castings, adopted by the American Society for Testing Materials, June 1922. They cover all classes of grey iron castings which are required to have a high strength, including those generally known as semi-steel castings, and also include details of the arbitration test-bar.

R. Stotz, *The Present Position of the Standardisation of Grey Iron Castings and Malleable Castings* (Giesserei Zeitung, September 19, 1922, vol. 19, pp. 537–544). The Charpy impact test is recommended as an excellent method of judging the quality of cast iron, and it also has the advantage that it is not necessary to perform the test on notched bars. The test-bars do not even need to be machined in any way, and the broken pieces left after the transverse test will serve quite well as impact test-bars. Diagrams are given showing the influence of phosphorus on the results of the transverse strength, deflection, and impact resistance. The transverse strength reaches a maximum with 0·2 to 0·3 phosphorus, and falls thereafter with increasing phosphorus. The deflection is little affected until the phosphorus exceeds 0·7, but impact strength falls as the phosphorus increases from 0·1 per cent.

L. W. Spring, *Addition of Cerium to Brass and Iron* (Paper read before the American Foundrymen's Association, June 1922: Foundry, July 1, 1922, vol. 50, pp. 542–544). The author gives the results of tests showing the influence of cerium on brass, cast iron, and converter steel.

G. K. Burgess and R. W. Woodward, *Thermal Stresses in Chilled Iron Wheels* (Bureau of Standards, Washington, Technologic Paper No 209, 1922, pp. 193–226). In order to study the stresses in wheels of different design and weight, car wheels of three different makes were electrically heated so as to produce an effect similar to that which results from continuous application of the brakes on heavy gradients.

J. M. Snodgrass and F. H. Guldner, *An Investigation of the Properties of Chilled Iron Car Wheels* (Illinois University Engineering Experiment Station, 1922, Bulletin 129). The results are given of a series of tests made to determine the strains produced within the wheel by mounting it on its axle, and by the application of wheel loads. Some of the physical properties of the irons used in the manufacture of chilled wheels are tabulated and a short description is given of the manufacture.

Properties of Steel Castings.—R. Schäfer, *Steel Castings as Material for Construction* (Giesserei Zeitung, August 15, 22, 1922, vol. 19, pp. 463–472, 475–482). A general review of the practice in the manufacture of steel castings, their heat treatment, and mechanical and magnetic properties. Specifications of various Government Departments, railways, and public authorities in Germany, France, Switzerland, Denmark, England, and the United States, of the conditions for the supply of steel castings are set forth in detail, and the chemical composition of castings suitable for a great variety of purposes is given. The article concludes with a bibliography of the German literature on the manufacture and properties of steel castings.

L. H. Fry, *Tensile Properties of Steel Castings* (Paper read before the American Society for Testing Materials, June 1922: Engineering, August 25, 1922, vol. 114, pp. 249–252). The paper is a report to a committee appointed to propose specifications for steel castings, and the work involved the collection of information regarding the tensile properties of steel castings furnished for railroad service, and the accurate measurement of the relation between extension and load during tension testing, particular attention being given to the true elastic limit. In two series of tests on uniform cast steel bars the values of the yield-point are more uniform and more consistent than the values found for the elastic limit. The uncertainty in the determination of the elastic limit is largely due to the fact, shown in the majority of the precision tests, that there is no constant proportionality between elongation and stress. That is to say, the annealed cast steels investigated have no true elastic limit, but behave as a plastic rather than an elastic material.

W. S. McKee and J. M. Blake, *Manganese Steel Castings in the Mining Industry* (Transactions of the Canadian Institute of Mining and Metallurgy, 1921, vol. 24, pp. 188–195). The properties and heat treatment of manganese steel and its uses in the mining industry are briefly outlined.

Tests, Properties and Uses of Steel and Steel Alloys.—F. Wüst, *Comparative Investigations of Acid and Basic Steel* (Mitteilungen a. d. Kaiser-Wilhelm-Institut für Eisenforschung, 1922, vol. 3, No. 2, pp. 29–55). The question of the relative value of basic and open-hearth steel has often been the subject of experiment and discussion, and the view is widely held that steels of exactly the same composition exhibit different characteristics, especially with regard to their tensile properties, according to whether they have been made by the basic or acid process. The object of the very comprehensive tests described in the paper was to ascertain whether by the ordinary methods of testing the material any difference could be detected between material of similar composition made by the different processes. Two samples, one of soft and one of medium hard acid steel, and two similar samples of basic open-hearth steel, furnished by Krupp, were the materials used. These were rolled into round bars of 20 millimetres diameter and into flat bars with a section of 10 × 30 millimetres. Thermal investigations were made, the magnetic properties were investigated, and the usual tensile tests and impact tests were carried out after various kinds of heat treatment. Brinell hardness determinations were also made, accompanied by examination of the grain size. The results of bending tests, forging tests, and punching tests are also recorded. The main conclusions are that in the range of the thermal and magnetic transformation temperatures no difference whatever can be detected in the steels manufactured by either process. The influence of heat-treatment on the tensile properties and structure was exactly the same whether the steel was of basic or acid origin. Such minor discrepancies as were noted could be accounted for by slight differences in the chemical composition and in the conditions of rolling. The results of the impact tests showed that the soft basic steel at higher temperatures was somewhat tougher than the soft acid. The medium hard steels showed no difference in their behaviour. The conductivity and magnetic tests revealed no differences that could be ascribed to the method of manufacture in any state of heat-treatment. The investigations are regarded as conclusive in showing that no distinction exists between the properties of steel whether manufactured by the acid or basic process.

L. Guillet, *Chromium Steels and their Recent Applications* (Revue de Métallurgie, Mémoires, August 1922, vol. 19, pp. 499–504). Describes the various uses to which chromium steel can now be put, and the special treatment and composition required for different purposes. These include tool and roller-bearing steel, both for balls and races; wire, magnets (in which chromium steels appear to give results equal to tungsten steels), stainless steel products, both as cutlery, surgical instruments, and culinary requirements, and for machinery and parts exposed to corroding influences. Chromium steel will weld easily, and the vexed question of whether electric or open-hearths are best for its production resolves itself into the fact that with due care either process will make good products.

K. Wendt, *Requirements and Properties of Structural Steel* (Zeitschrift des Vereines Deutscher Ingenieure, June 17, 24, July 1, 1922, vol. 66, pp. 606–618, 642–648, 670–674). The article deals with the development of high quality steels and steel alloys, how to impart to them their special properties and the methods of testing their suitability for the particular purposes for which they are to be employed, as regards their mechanical, physical, and chemical properties. Some results of forging tests on a chromium steel are given which show the remarkable effect of forging in increasing the tensile strength and, still more, the impact resistance of the material. A forged and heat-treated bar of chromium steel, 180 millimetres in diameter, showed a tensile strength of 60 kg./mm.^{2} and an impact resistance of 10·4 mkg./cm^2. After forging down the bar to 60 millimetres diameter and heat-treating again, its strength was 73 kg./mm.^{2} and impact resistance 20·5 mkg./cm.^{2} (nearly 100 per cent. higher). Advantage was taken of this forging effect when, owing to the scarcity of nickel during the war, gun tubes could no longer be made of nickel-chrome steel. Chromium steel ingots were forged and hollow-drawn in a press, instead of being forged solid and bored out, and such tubes had a bursting resistance equal to that of bored tubes of nickel-chrome steel. Some notes on specifications and standardisation are given in conclusion.

The Strength of Railway Bridge Materials (A discussion before the British Association, September 1922: Iron and Coal Trades Review, September 15, 1922, vol. 105, pp. 386–387). The following papers were read and discussed: A. C. Cookson and J. S. Nicholas, "The Strength of Railway Bridges, with Special Reference to the Proposals of the Ministry of Transport." C. Gribble, "Present-Day Problems and Tendencies in Railway Bridge Design." J. S. Wilson and B. P. Haigh, "The Influence of Rivet-Holes on the Strength and Endurance of Steel Structures." In this latter paper the authors point out that the members in tension were obviously weakened by the numerous rivet-holes that pierced the sections, but the ratios of reduction were not at present well established. The authors had carried out experiments on model plates $1\frac{1}{2}$ inch × $\frac{1}{16}$ inch, with and without perforations, these dimensions having been adopted to reproduce the proportions of a typical plate in a bridge member 9 inch × $\frac{3}{8}$ inch, with holes to suit $\frac{7}{8}$ inch rivets. The tests were carried out in a Haigh alternating stress testing machine, adjusted to apply stresses pulsating 2000 times per minute. The metal used in the tests was a mild steel with a comparatively low yield point. The experiments showed: (1) That in mild steel such as was used in practice, fatigue would not occur under pulsating stresses unless these reversed in direction, acting as push as well as pull, at least locally, where the stresses were modified by the influence of the perforations; (2) that in steels of higher tensile strength fatigue might occur, although the stresses acted always in the one direction and kept well below the yield point; (3) that fillets and perforations produced locally the conditions required to promote fatigue in mild steels; (4) that the dangerous influence of a hole, in promoting fatigue in a mild steel plate, was less than hitherto had been believed; and (5) that pierced plates, in failing from fatigue, cracked at right angles to the line of the applied pull, and not necessarily across the narrowest sections between the holes. It was concluded that the experiments endorsed the view—based on practical experience—that the danger of fatigue was decidedly less than often had been supposed.

Weakening of Steel Rails caused by Welded Bonds (Engineering News-Record, March 30, 1922, vol. 88, pp. 524–525). Comparative tests have been made by the Pittsburgh Testing Laboratory to determine the influence on the strength of rails of welding on copper bonds. The tests were made on 4½ foot lengths of rail under standard drop test machines of the American Railway Engineers' Association. Bonds were attached to about half the number of the test-pieces, in some cases with one of the terminals at mid-length of the specimen and in others with the two terminals symmetrically placed with regard to the mid-length of the rail. Under test the unbonded rail specimens broke on the third to the fifth blow while the bonded specimens broke on the first blow, the form of the fractures in the latter cases being quite abnormal.

Effect of Sulphur on Rivet Steel (Preliminary Report presented to the American Society for Testing Materials, June 26, 1922, 32 pp.). Basic open-hearth rivet steel was used for the experiments, the sulphur ranging from 0·0282 to 0·0834 per cent. in thirteen specimens, while for a fourteenth material was taken containing 0·1793 per cent. sulphur. The bars were tested in the natural, the annealed, and the quenched state. The impact values given by the Charpy and the Izod tests are recorded in diagrams, and others show graphically the effect of sulphur on the hardness and other mechanical properties.

E. E. Thum, *Effect of Sulphur on Rivet Steel* (Chemical and Metallurgical Engineering, May 31, 1922, vol. 26, pp. 1019–1024). The author discusses the results of the tests carried out by the Committee of the American Society of Testing Materials on the influence of sulphur on rivet steel.

C. E. Stromeyer, *Fatigue of Metals* (Proceedings of the South Wales Instutute of Engineers, July 20, 1922, vol. 38, pp. 285–331). In a previous paper by the author the empirical law of fatigue is expressed by the formula $S = \mathrm{Fl} + C(10^6/n)^{\frac{1}{4}}$. S is the alternating stress which will cause failure after being repeated n times, Fl is the fatigue limit of the material, and C is a constant. Particulars are given of a new testing-machine for determining the fatigue limit calorimetrically. It has been found that, as soon as the fatigue limit is reached, what may be called molecular friction takes place in the sample which generates heat, and this can be determined either calorimetrically or by means of very sensitive thermocouples and galvanometers; at the same time the elastic properties of the material undergo a change which can be determined by suitable instruments. The results of Wöhler's tests dealing with permanent stresses in excess of the added fatigue stresses are shown in diagrams, together with the author's similar tests on mild steel. The author's tests on mild steel are the only ones which have ever been made for the determination of fatigue limits of permanently stressed samples. They show that with an average compression stress of 4·46 tons the fatigue limit was reached with an alternating stress of plus and minus 11·4 tons, the range of stress being from 15·86 tons compression to 6·94 tons tension. With no permanent stress the limit was reached with 10·87 alternating stress, and with an average tension stress of 4·47 tons the fatigue limit was reached with 9·32 tons alternating stress, the range being from 4·85 tons compression to 13·79 tons tension.

W. Müller and H. Leber, *Fatigue of Normalised and Heat-Treated Carbon Steels* (Zeitschrift des Vereines Deutscher Ingenieure, June 3, 1922, vol. 66, pp. 543–546). The investigation was on a series of high quality carbon steels with carbon ranging from 0·09 to 1·31 per cent. In the normalised state the carbon steels show a lower resistance to fatigue as the carbon is increased. By suitable heat treatment the resistance to fatigue in hypoeutectoid steels is increased, and the improvement in resistance is greater the higher the carbon. The temperature of heat-treating depends on the carbon content. In each kind of steel the tensile strength and hardness bears a definite relationship to the maximum resistance to fatigue; the higher these values are the greater the resistance. With suitable treatment carbon steels will acquire nearly the resistance to fatigue as nickel-chrome steels of the same tensile strength.

H. F. Moore and T. M. Jasper, *Recent Developments in Fatigue of Metals* (Iron Age, September 28, 1922, vol. 110, pp. 779–784). The latest type of testing machine for making reversed bending tests, as used in the laboratories of the University of Illinois, is described, and important factors in fatigue testing are discussed.

A. Mesnager, *The Deformation and Fracture of Solid Bodies* (Revue de Métallurgie, Mémoires, June, July 1922, vol. 19, pp. 366–378, 425–436). The apparent elastic limit of mild steel depends wholly upon the amount of the principal shearing stress, or, in other words, on the difference between the greatest and the least predominant stress. The formula, based on erroneous conceptions, which fixes the limiting stresses which can be borne at four-fifths of the shearing stress should be abandoned. Not more than one-half that stress can be allowed with safety. A distinction must be made between the rupture of equilibrium which manifests itself by permanent deformation, and the stresses which cause actual fracture. The practical conclusions of such views are summarised.

F. B. Foley and S. P. Howell, *Neumann Bands as Evidence of Action of Explosives upon Metal* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, No. 1186–S, 25 pp.). It has been stated that observations on the Neumann bands in the structure of fractured metals may serve to distinguish the speed of breakage and hence, between fracture caused by an explosion and that caused by an ordinary strain. To test this statement a series of experiments has been carried out by a Committee of the Division of Engineering of the United States Research Council, to determine the influence of velocity of impact on Neumann bands. These experiments serve to show that the number of Neumann bands increases with the velocity of impact until this exceeds 2296 metres per second. With increased velocities no increase in the number of the bands is formed. The number of bands does not bear any apparent relationship to the amount of plastic deformation caused by the impact. The conditions of the experiments were, however, inconclusive in definitely deciding the truth or otherwise of the general statement.

T. Baker, *Some Thoughts on the Elastic Limit* (Journal of the Birmingham Metallurgical Society, vol. 8, No. 1, pp. 1–15). In its original meaning the elastic limit is that stress beyond which a body fails to regain its original size and shape after the removal of the distorting force. The experimental realisation of this definition is embodied in what is called the limit of proportionality, or the point at which the strain ceases to be proportional to the stress. In engineering practice there is what may be termed the commercial elastic limit —the well-known yield point which is generally slightly higher than the limit of proportionality ; it is the point at which there is a considerable increase in the strain with little or no change in the stress, and is characterised by a distinct step in the load-strain diagram. This laxity of definition has been the cause of much misunderstanding and confusion in the past, and it is highly desirable that steps should be taken to define the commercial elastic limit or yield point in some more definite way. The effect of internal strain on the form of the load-strain diagram is shown.

R. Fleury, *The Rôle of the Modulus of Elasticity in Engineering Construction* (Revue de Métallurgie, Mémoires, May 1922, vol. 19, pp. 289–302). The modulus of elasticity based upon observations on grade of iron and steel commonly used is too often employed empirically only when it is sought to take it into account in the new qualities of steel, and of alloys which modern metallurgy has rendered available. These new qualities of resistance and tensile strength must not be relied upon for the indefinite and continuous reductions of mass which modern engineering construction seeks. The elastic modulus, the most important property of strength, must be ascertained in relation to the actual reduced sections employed, and not estimated from conditions in which the masses are far greater.

F. F. McIntosh, *Fibre in Iron and Steel* (Transactions of the American Society for Steel Treating, July 1922, vol. 2, pp. 856–868). The author points out the importance of fibre or grain in the performance of iron and steel in service, and indicates the factors which govern its formation and character.

W. C. Unwin, *Influence of the Distance between Supports and Cross-*

Section on the Percentage Elongation of Test-Pieces (Report of the Engineering Standards Committee, French authorised translation: Revue Universelle des Mines, March 1, 15, 1922, vol. 12, Series 6, pp. 430–443, 492–506). The French text, with tables, of the experimental data found by Professor Unwin and of the conclusions derived therefrom.

H. L. Heathcote and C. G. Whinfrey, *Tearing Tests on Metals* (Chemical and Metallurgical Engineering, August 16, 1922, vol. 27, pp. 310–311). To refer to working stress in metals as being so many pounds or tons per square inch is convenient and satisfactory as long as the square inch does its work and carries its load fairly uniformly. The load which at heavy stress concentrates at parts where the section changes may, however, greatly exceed the uniformly distributed load the metal can bear and tearing occurs. A new form of tearing test, taking these considerations in view, is described. The impact test on notched bars is described as resembling more closely tearing strength than tensile strength. In machining the action of removing metal is in itself a manifestation of tearing resistance.

E. D. Campbell, *A Brinell Machine Attachment for Use with Small Specimens.* (This Journal, p. 193.)

R. L. Smith and G. E. Sandland, *An Accurate Method of Determining the Hardness of Metals with Particular Reference to those of a High Degree of Hardness* (Proceedings of the Institution of Mechanical Engineers, 1922, vol. 1, pp. 623–641). The authors have in their investigations assumed that hardness is proportional to the load necessary to produce a constant sized impression. Theoretically it should be possible to deduce from the Brinell formula the load to give a constant impression, since if the hardness numbers obtained were truly relative they should be proportional to the loads giving identical impressions. This is not actually the case, but it has been found that by a suitable modification of the Brinell formula it is possible to obtain truly relative hardness figures from which may be calculated the load required to give a constant impression. The test is carried out with a 10-millimetre ball, and the modified hardness number is calculated according to the formula: Brinell hardness number at 1000 kg. $\times \left(0{\cdot}9 + \frac{0{\cdot}4}{d^2}\right)$, where d is the diameter of the impression in millimetres. From this formula may be calculated the load required to give any size of impression; curves are plotted showing loads giving a constant impression of 2·5 millimetres diameter. It was still found that in the higher ranges the results were unsatisfactory, due to the deformation of the ball. It was found possible to use an uncut diamond with a natural pyramidal point, and to calibrate it so as to obtain the hardness figures of materials over the complete range. The most reliable method of obtaining hardness figures above 550 modified Brinell hardness is by means of a spherical diamond, but owing to the difficulty of producing such diamonds the uncut diamond is more practicable and produces impressions giving results correct to within 3 per cent.

S. P. Rockwell, *The Testing of Metals for Hardness* (Transactions of the American Society for Steel Treating, August 1922, vol. 2, pp. 1013–1035). The author compares the results obtained by the Brinell, scleroscope, and Rockwell hardness testing machines on various metallic products under varying conditions. The possibilities of converting the readings of any one of the machines into terms of any of the others are also dealt with.

E. F. Lake, *Toughness in Relation to Hardness of Metals* (Forging and Heat-Treating, July 1922, vol. 8, pp. 313–315). The principles of the Frémont, the Stanton, the Charpy, and the Izod impact tests are described, and the methods are diagrammatically illustrated. The methods and principles of wear-testing are also described.

F. E. Foss and R. C. Brumfield, *Some Measurements of the Shape of Brinell Ball Indentation* (Paper read before American Society of Testing Materials, June 26, 1922, 24 pp.). A number of impressions made by the Brinell ball in a variety of metals were accurately cross-sectioned with the object of studying the results obtained by means of the depth-gauge measurement, and comparing them with those obtainable from the measurement of the diameter with the microscope. The diameter measurement made in the ordinary way gives very satisfactory results, but the depth-gauge readings do not give accurate hardness numbers, especially on the harder metals, unless calibrated in such a way as to give results under full load readings. The depth-gauge then offers certain advantages, especially as regards speed of taking observations. The results also throw light on the effect of swell at the edge of the impression, the effect of varying the load and the time during which the load is held, the rate of application, and the distorting effect on the ball.

J. C. W. Humfrey, *Toughness in Steel* (Paper read before the Birmingham Metallurgical Society, May 11, 1922: Iron and Coal Trades Review, May 19, 1922, vol. 104, p. 746). It is shown that brittleness in carbon steels, as represented by sudden fracture of the notched-bar test-piece, might be due either to the lack of normal adhesion between the crystals or to the cleavage weakness in the crystals themselves. When a sudden failure occurred it was accompanied by a shattering effect occurring in advance of the main crack. In medium and high-carbon steels brittleness might result from the normal structure of the pearlite, in which brittle cementite lamellæ were embedded in allotriomorphic ferrite crystals. By heat treatment it is possible to modify the relative structure. But severe quenching of carbon steels is only applicable to small parts, and it is only in such articles that a toughness due to the granular sorbitic structure formed by the severe quenching and subsequent reheating could be obtained. With larger articles the desired effect has been secured by Sandberg's sorbitic process for cooling the steel by a blast of air or of air and atomised fluid. The author has devised a machine which autographically records the relation between the bending moment and bending angle throughout the test. Experiments with it show that materials can be classified into two distinct groups: (1) Those in which fracture, when once started at the bottom of the notch, takes place gradually and the material offers a definite resistance to the propagation of the crack. (2) Those in which fracture occurs suddenly and the crack is rapidly propagated through the specimen without the application of further external force. It is suggested that this difference is a better indication of toughness or brittleness than the figure for the total energy as obtained in an impact machine.

A New Impact Hardness Testing Machine (Allgemeine Automobil Zeitung, October 22, 1921, pp. 31–32). Describes a new apparatus designed by R. Baumann of the Technical Academy, Stuttgart. The cost is said to be about one-fifth that of the Brinell hardness testing machine, and it is of light weight and easily handled.

J. M. Lessells, *A Discussion of Impact Testing Methods and the Results obtained* (Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 659–672). After briefly describing the Frémont, Charpy, Izod, and Stanton testing machines, the author gives the results obtained with the Izod machine on low carbon, medium carbon, nickel and nickel-chrome steels. The author concludes that the Izod impact test is one of the most sensitive mechanical tests so far introduced to determine the kind of heat treatment given to a material. It shows up characteristics in certain materials which tensile tests do not indicate. The impact test corresponds along with other physical properties such as reduction of area to the variation in heat treatment, and is therefore valuable for confirmatory purposes. The impact test offers valuable evidence, by observation of the fracture, relative to the heat treatment undergone by the material.

D. J. McAdam, *Impact Tests of Metals* (Paper read before American Society of Testing Materials, June 26, 1922, 16 pp.). Impact testing machines of various types, including repeated impact and static resilience testing machines are briefly described, with a discussion of the effect of weight of hammer and anvil, the striking velocity on impact resistance values, and of the relations of repeated to single-blow impact, and of impact resistance to static resistance. The forms and dimensions of impact specimens in common use are also described.

C. E. Margerum, *Measurement of Pressures caused by Impact* (Paper read before the American Society for Testing Materials, June 26, 1922, 13 pp.). The three principal methods available for the measurement of the pressures produced by impact are: the time-space or deceleration method, the method by recording the amount of deflection of elastic bodies, and the method using the principle of deformation of calibrated reference pieces subjected to the same impact pressures as the test specimen. For practical purposes, the third method furnishes a simple and accurate means.

A. Elmendorf, *Measuring Forces in Impact* (Paper read before the American Society for Testing Materials. June 26, 1922, 7 pp.). Of two available methods, (1) supporting the ends of the beam on springs and obtaining autographic records of spring compression and beam deflection, and (2) supporting the beam rigidly at the ends, and obtaining space-time curves of the falling hammer, the author concludes that the second is more feasible.

H. F. Moore, *Measurement of the Force of Impact by Means of the Elastic Stretch of a Steel Bar* (Paper read before the American Society for Testing Materials, June 26, 1922, 4 pp.). The problem of measuring the load applied to a specimen in a few hundredths of a second was solved by devising a simple recording extensometer which measures the elastic stretch of a steel bar subjected to the same load as the specimen under study.

F. C. Langenberg and N. Richardson, *Significance of the Impact Test* (Paper read before the American Society for Testing Materials, June 26, 1922, 9 pp.). The authors point out that the many attempts to correlate the impact test with other tests have failed to establish a definite relation between the static tension test and the dynamic impact test. Regardless of the type of impact machine employed, or form of specimen used, the essential result is the measure of the amount of energy absorbed by the specimen. In comparing static and dynamic tests, therefore, the same essential data should be noted in both cases. In the ordinary static tension test such data are not recorded, and it is therefore impossible to find any definite relationship between the values usually recorded in the tensile test and the impact test. From a large number of tests the authors conclude that the elastic limit and tensile strength of a wide variety of annealed and heat-treated steels do not bear any relation whatever to the work expended in the rupture of Charpy impact test specimens. The work required to break any given section cannot be calculated from the work required to fracture a test-bar of different dimensions, yet, in the tensile test, if the elastic limit is determined on a given specimen, the result can be safely applied in calculating the dimensions of any member of the structure. The value of the impact test is nevertheless vital in judging the properties of a given material for certain specific purposes, and instances are given where the acceptability of a forging is judged from the impact test alone.

H. S. Rawdon and S. Epstein, *Some Observations on the Nick-Bend Test for Wrought Iron* (Paper read before the American Society for Testing Materials, June 26, 1922, 24 pp.). The investigation consisted in the fracturing under known conditions of nicked bars of different grades of wrought iron, the composition, mechanical properties, and structure of which had been carefully determined. The appearance and nature of the fracture produced under different methods of testing are illustrated and discussed.

C. L. Warwick, *American Practice in Notched Bar Impact Tests of*

Metals (Paper read before the American Society for Testing Materials, June 26, 1922, 20 pp.). In anticipation of the eventual standardisation of machines and specimens for notched bar impact tests, a committee of the American Society for Testing Materials circulated a questionnaire among testing engineers for the purpose of ascertaining their present practice with regard to impact testing. The questions and replies are published in full, with dimensioned sketches of test-pieces employed.

R. Baumann, *Tests on Ingot Iron* (Zeitschrift des Vereines Deutscher Ingenieure, September 2, 1922, vol. 66, pp. 825–826). Tensile tests and impact tests were carried on test-bars of ingot iron, with the composition of carbon 0·06, silicon trace, manganese 0·13, phosphorus 0·010, and sulphur 0·026 per cent. The tests were performed at temperatures ranging from 18° C. to 600° C., and the results are given in tabular form and plotted as curves. The material in general behaved in the same manner as ordinary mild steel under the same conditions of test. Above 200° the elongation values were very high.

L. Jannin, *A Rapid Method for the Determination of the Elongation and Impact Resistance of Steel by the Bending of a Notched Bar* (Bulletin de la Société d'Encouragement, July 1922, vol. 134, pp. 646–656). A ready method for determining roughly the elongation of a steel material is to prepare a bar about 60 millimetres long and 10 × 10 millimetres square with a radial notch cut in one side at the centre of the bar, with a radius of 5 millimetres. The bar is held by one end in a vice and the free end is struck with a hammer on the notched side, bending the bar until a crack becomes visible at the bottom of the notch, at which point the width of the bar will have contracted. If W is the width of the bar and w the width at the bottom of the notch after bending, then $\frac{W-w}{W}$ gives the elongation per cent. very approximately; or if the full width is 10 millimetres then $W-w$ equals the elongation per cent. in tenths of millimetres; thus, $W = 10$, and say, $w = 7{\cdot}2$, then $10-7{\cdot}2 = 2{\cdot}8$ or 28 per cent. elongation. The bar need not be of the exact width of 10 millimetres, since with a toleration of ± 0·2 millimetre the calculation is still sufficiently accurate, thus $10{\cdot}2-7{\cdot}2 = 3$, *i.e.* 30 per cent. elongation. Further, since the resistance of a steel is approximately proportionate to its Brinell hardness, it has been found that by multiplying the hardness number of the specimen by the supplement of the angle of bending, and dividing the product by 1000, a number is obtained which the author terms the coefficient of impact, which represents very approximately the resistance to impact of the steel. The results of a number of tests are given in a series of tables.

A. Lundgren, *Influence of Different Conditions of Annealing on the Impact Resistance of Mild Steel* (Jernkontorets Annaler, 1922, vol. 77, pp. 315–324). The results of an investigation carried out at the State Testing Laboratory at Stockholm are reported. Two kinds of mild steel, marked A and B, were used, of the following composition :

	Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
A	0·10	0·01	0·45	0·026	0·012
B	0·10	0·26	0·31	0·022	0·012

A was practically silicon-free, and B was treated by the addition of silicon. Both steels were rolled down into round bars 18 millimetres

No.	Treatment.		Steel A. Silicon-free.					Steel B. Si = 0·26.				
			Elastic Limit. Kg. per Mm².	Breaking Strength. Kg. per Mm².	Elongation per Cent.	Reduction of Area per Cent.	Impact Resistance Kgcm/mm².	Elastic Limit. Kg. per Mm².	Breaking Strength. Kg. per Mm².	Elongation per Cent.	Reduction of Area per Cent.	Impact Resistance Kgcm/mm².
1	Untreated		32·9	39·7	30·0	72	14·8	34·3	42·4	29·4	74	15·
	Heated to	Rate of Cooling.										
2	900°	Free in air .	31·8	44·5	25·0	64	15·1	34·4	41·5	26·1	70	14·
3	900°	10° per 2 min. .	29·5	40·8	25·5	64	6·5	28·7	38·9	26·3	68	12·
4	900°	10° per 10 min. .	...	...	..	...	3·0	...	...	...	...	8·
5	900°	10° per 10 min. to 750°, thence free in air .	31·1	40·1	28·1	68	12·1	30·7	41·4	27·1	66	13·
6	830°	Free in air .	32·6	44	27·3	66	9·9	29·1	41·4	28·6	73	15·
7	830°	10° per 2 min. .	26·9	40·7	27·1	65	4·5	28·7	39·4	28·3	71	12·
8	830°	10° per 10 min. .	...	...	...	...	4·3	27·0	38·4	28·8	70	10·
9	830°	10° per 20 min. .	27·7	34·7	31·3	71	2·8	28·0	38·0	29·5	70	8·
11	900°	Free in air, then re-heated and cooled as No. 8	31·2	36·6	30·7	73	4·3	29·6	38·3	29·6	71	11·
12	780°	Free in air .	30·7	43·8	25·7	67	9·5	32·6	41·6	28·3	71	15·
13	780°	10° per 2 min. .	24·8	40·5	27·2	68	3·9	33·1	39·0	28·9	65	11·
14	780°	10° per 10 min. .	25·9	35·6	29·0	73	2·4	...	...	...	...	10·
15	780°	10° per 20 min. .	...	...	...	...	1·6	...	...	...	...	9·
17	900°	Free in air, then re-heated and cooled as No. 14	29·0	35·7	30·5	70	2·7	30·5	38·4	29·9	74	9·
18	750°	Free in air .	25·5	37·8	29·2	70	10·0	32·4	40·0	28·0	71	15·
19	750°	10° per 2 min. .	27·6	35·7	29	71	5·7	31·8	39·1	30·5	71	12·
20	750°	10° per 10 min. .	24·3	35·0	28·8	71	3·7	32·0	38·9	30·5	72	11·
21	750°	10° per 20 min. .	...	...	...	...	1·7	...	...	...	...	9·
23	900°	Free in air, then heated at 670° for 7 hours .	30·7	40·8	26·3	73	7·2	28·1	38·2	27·7	76	14·
24	900°	Free in air, then heated at 640° for 10 hours .	29·6	37·7	30·6	76	10·8	30·9	38·8	29·5	75	13·

diameter. From these a number of test-bars were cut for tensile tests and Charpy impact tests, subsequent to annealing at different temperatures and cooling at different speeds. The length of the tensile test-bars was 180 millimetres, and of the impact test-bars 110 millimetres. These latter were machined to 10 × 10 millimetres square, and were notched to a depth of 5 millimetres at the centre, and were then broken in a Charpy pendulum machine. The bars were heated to different temperatures, namely 900°, 830°, 780°, and 750°, from which temperatures some of the bars were cooled free in air, with a cooling rate of 10° per five seconds, and others were cooled more slowly at rates of 10° per two minutes, ten minutes, and twenty minutes.

The above table shows the main results of the tests.

Micrographs of the steels in the different annealed states are shown and discussed. Summarising the conclusions, it is shown that two mild steels, both with a carbon content equal to 0·1 per cent., one of which is practically silicon-free and the other with silica at 0·26, after annealing at different temperatures and cooling at different speeds, are affected in particular as regards their impact resistance. When cooled free in air both materials show high impact resistance. When cooled slowly from temperatures above the critical point Ac1 (about 720°), both materials show a great diminution in the impact resistance. Likewise, the impact resistance is diminished after heating for longer periods at temperatures under the critical point Ac1.

L. Aitchison, *The Testing of Drop Forgings* (The Drop Forger, February 1922 (Birmingham); Forging and Heat-Treating, April 1922, vol. 8, pp. 188–192). Discusses the relative importance of chemical, mechanical, microscopic, macroscopic, service and design tests on forgings. The design test consists in looking not at the forging but at a drawing which shows the dimensions of the forging after it has been machined. This test is more applicable to those forgings that are exposed to fatigue or alternating stresses than to those that support static or steady loads. The basis of the test is undoubtedly the uneven distribution of stress that is brought about by any sudden change of section, or notch, or sharp corner in the forging. The variable stress distribution applies both to fatigue and to static stresses, though there is no doubt that for fundamental reasons the uneven distribution is more dangerous when the stresses imposed are alternating. It is now known very adequately that, if a drop forging is machined so as to include a sharp corner, or a very sudden change of section, or if it is threaded with badly cut threads, or provided with a key way having an inadequate radius at the root, and then is stressed, the stress at the points mentioned above may rise to a value two, three, or even more times the normal stress in the metal at places of normal contour. These abnormal stresses effectively reduce the real strength of the machined part, and therefore implicitly tend to weaken the drop forging.

J. H. S. Dickenson: *Some Experiments on the Flow of Steels at a*

Low Red Heat, with a Note on the Scaling of Heated Steels. (This Journal, p. 103.)

H. Edert, *High-Temperature Tests on Special Steels* (Stahl und Eisen, June 22, 1922, vol. 42, pp. 961–968). The author reports the results of a series of tests to determine the mechanical properties of special steels at high temperatures. The steels tested included a nickel-chrome, a chrome-vanadium, and rustless steels. The composition of the steels is given, and the percentages of the principal elements are shown in the above table.

No.	C.	P.	S.	Ni.	Cr.	V.	
1	0·31	0·010	0·025	1·90	1·53	...	Quenched in oil and annealed
2	0·21	0·018	0·050	4·03	1·69	...	
3	0·37	0·006	0·046	0·03	2·38	0·58	
4	0·12	0·006	0·048	1·49	15·8	...	Quenched in oil from 900° and from 650°
5	0·28	0·008	0·048	5·76	20·6	...	Quenched in oil from 1200°

The specimens were in the form of bars turned to 25 millimetres

Steel No.	Temperature. Deg. C.	Breaking Stress. Kg.mm².	0·2 per Cent. Limit of Elasticity. Kg.mm².	Elongation. $l = 5\,d$. Per Cent.	Reduction of Area. Per Cent.
1	20	86	71	24	67·5
	500	44·2	29·3	28·4	88
	600	24·5	11	47·4	91
	700	9·4	...	41·2	84
2	20	77·8	66·2	25	70
	500	43·3	28·6	28·2	82
	600	20·1	9·5	50·2	86
	700	8	...	57·8	54
3	20	127·7	117·4	13·5	44
	500	77·5	55·8	18·4	62
	600	41·4	15·9	34·8	75
	700	7·9	...	80·2	95
4	20	79·4	65·2	21	60
	500	50·9	39·2	19·5	64
	600	25·6	14·1	39·2	88
	700	8·2	...	119·0	91
5	20	87·7	38·2	60·9	41
	500	62·9	18·3	45	50
	600	49·3	17·8	20	24
	700	22·8	14·6	8·1	13·5
	800	15·0	11·5	...	10

diameter, and they were stretched at a speed of 1 per cent. of their length per minute.

None of the tensile properties were affected to a great extent until the temperature of 300° C. was exceeded. The above table shows the results at intervals of temperature above 300°.

The impact resistance and Brinell hardness were also measured on all the steels. The chrome-vanadium steel (No. 3) shows the highest tensile strength of any until 600° is reached, but the elongation and impact resistance (4 mkg. per cm.^{2} at 600°) are considerably lower than the values given by the other steels. The following were the impact resistances of the steels at the various temperatures :

Steel No.	Temperatures.			
	20°	500°	600°	700°
	Impact Resistance, Mkg. per Cm^2.			
1	10	6·6	14	15
2	9·5	6·5	10	13·25
3	3·5	3·5	4	8·5
4	10	6·5	5·75	7·5
5	11·5	9·25	10	10·75

M. A. Hunter and A. Jones, *Some Electrical Properties of Alloys at High Temperatures* (Paper read before the American Electrochemical Society, September 1922). The specific resistances of a number of metals and alloys which are in commercial use have been determined over the range from room temperature to 1000° C. The materials used in the heating elements of commercial units may be divided into two classes. The first class comprises those which require materials with high specific resistance at the operating temperature. The second class includes those materials which, in addition to having a high specific resistance unit, must also withstand oxidation. The first class includes nickel, copper-nickel, and iron-nickel alloys, and can be used for heating units up to 500° C. The second class includes nickel-chromium, nickel-iron-chromium, and iron-chromium alloys, and may be used for temperatures in excess of 500° and up to 1100° C. Some information on the relation between the resistance of bright and oxidised wire is also included.

H. J. French, *Strength and Elasticity of Boiler Plate at Elevated Temperatures* (Chemical and Metallurgical Engineering, June 28, 1922, vol. 26, pp. 1207–1209).

H. J. French, *Effect of Rate of Loading on Tensile Properties of Boiler Plate* (Chemical and Metallurgical Engineering, August 16, 1922, vol. 27, pp. 309–310). The question of whether steel is susceptible to variations in rate of loading at operating temperatures of steam superheaters, crude oil stills, nitrogen fixation apparatus, and similar appliances is a very important one. As the result of such investigations as were available, more especially on railway firebox steel at various temperatures, it is concluded (1) that up to and including blue-heat range the tensile properties are independent of the rate of loading; (2) at 465° C. (870° F.) tensile strength appears to increase slowly with rate of loading, ductility remaining practically constant.

H. J. French, *Boiler Plate after Cold-Work or Work at Blue Heat* (Chemical and Metallurgical Engineering, August 2, 1922, vol. 27, pp. 211–215). The effect of cold-working is maintained until relatively high temperatures are reached (465° C.; 870° F.). Changes in proportional limit are more marked. In the blue heat range (295° C.; 565° F.) the increase in proportional limit due to cold-work reaches the very high value of 150 per cent. in the marine grades of boiler plates and nearly 200 per cent. in firebox grades, the elongation remaining constant. "Bluing" cold-finished products, such as thin-walled seamless steel tubes, materially increases the elastic ratio with little effect on other tensile properties. A firebox steel had its limit of proportionality increased about 20 per cent. A short tempering at somewhat higher temperatures gives but little improvement. Working steel within temper-colour ranges has always been considered to be deleterious and even dangerous, and many authorities are quoted to this effect. Yet thousands of boiler plates must have been worked more or less at blueness and failures are rare. A number of experiments are given on the effect of blue-working, the outcome of which appears to be that the range of proportionality is not actually altered but merely shifted. What is gained in tensile strength is lost in compression strength.

H. C. Knerr, *Determining Coefficient of Expansion with a Metallurgical Microscope* (Chemical and Metallurgical Engineering, April 5, 1922, vol. 26, pp. 644–646). The thermal expansion was determined with the aid of an inverted microscope, by measuring the difference in expansion between the sample and pieces of steel and of duralumin, placed on each side, the temperature being regulated by a water-bath. Observations were taken through glass windows in the bottom of the bath. Preliminary readings were taken at intervals, until a number of consecutive readings were identical, showing that the temperature of the specimen had become constant.

L. Guillet and J. Cournot, *On the Variation in Mechanical Properties of certain Metals and Alloys at Low Temperatures* (Revue de Métallurgie, Mémoires, April 1922, vol. 19, pp. 215–221). A series of experiments was carried out on five classes of alloys: (1) Iron alloys, (2) ferro-nickels, (3) copper alloys, (4) cobalt, and (5) aluminium alloys. The temperatures employed were 20°, −20°, −80°, and −190° C., and the tests were for hardness and for impact resistance, carried out respectively by the Brinell method in a Frémont press and by the Guillery method on Mesnager test-bars. Of the first two classes of material there were selected pure electrolytic iron, mild and semi-mild steel, hard steel, case-hardened nickel steel, and nickel-chromium steel, both annealed and air-hardened, besides a range of iron-nickel alloys. The increase in hardness at low temperatures was more particularly noticeable in iron alloys, and non-ferrous alloys were not sensibly affected as regards their impact resistance by lowered temperatures. Indeed aluminium and duralumin were slightly stronger in this respect at lowered temperature which leaves causes of failure in such metals to be sought elsewhere. In the iron alloys the effect of cold does not appear until temperatures in the neighbourhood of —110° C. are reached, but such variations as occur bear a direct relation to the amount of iron present, and more particularly to the ferrite content. Pearlitic nickel steels also exhibit great brittleness at low temperatures. Comparisons are instituted between the results obtained from these experiments and the conclusions of Sir R. Hadfield and Sir J. Dewar (*Proceedings of the Royal Society*, 1904, vol. 47, pp. 326–336). The present conclusions reached are: (1) That in the experimental conditions involved, tenacity varied always in the same direction as the hardness, but that the coefficient of proportionality of these two properties varied strangely with the temperature. (2) As regards the parallelism between elongation and impact resistance, this is hardly borne out in the case of electrolytic iron, ordinary steel, and air-hardened steels, while it certainly fails completely in the case of nickel steels and pure nickel. In Hadfield and Dewar's experiments the ductility was constant up to 3·8 per cent. of nickel and 0·2 per cent. of carbon. In the present experiments it was found, on the contrary, that in a case-hardened nickel steel with 2·3 per cent. of nickel and 0·06 per cent. of carbon, the impact resistance fell from 31·2 to 3·5, and this also occurred with chromium-nickel steels. It is concluded from this that at the temperatures in question the variations in elongation and in impact resistance bear, in numerous instances, no relation whatever to each other.

P. Chevenard, *Investigation on the Brittleness of Ferro-Nickels at Low Temperatures* (Revue de Métallurgie, Mémoires, April 1922, vol. 19, pp. 209–214). In plant for the liquefaction of air by the Claude process parts are subjected to relatively sharp stresses at temperatures of —180° C., at which practically the mildest steel becomes extremely brittle. Experiments made by C. E. Guillaume on ferro-nickel, an alloy non-brittle at ordinary temperatures, bore out the expectation that such alloys would maintain their non-brittleness at low temperatures. While the problem was thus empirically solved many details remained to be considered. A series of experiments was therefore carried out on ferro-nickel alloys practically free from carbon and silicon, and only containing such small amounts of manganese as to render them forgeable. The nickel varied from 35 to 98 per cent., and the experiments were made at temperatures of 20°, — 79°, and — 190°, and testing effected by means of a Frémont impact machine. As the result of these experiments it was established that brittleness at low temperatures is a specific property of iron in both its allotropic states, being encountered in all the alloys rich in iron. The impact resistance of all steels proper (in alpha state) reaches a minimum at temperatures below — 100° C., while that of austenite steels containing over 60 per cent. of iron (in the gamma state) similarly become intensely brittle at low temperatures. On the other hand, nickel and ferro-nickels containing 40 per cent. of nickel and over are perfectly soft at all temperatures. The presence of a certain amount of carbon and manganese does not affect this property, whereas the addition of chromium renders the alloys more brittle. For special parts in freezing machines, such, for instance, as valves, special properties can be induced by special mixtures. To obtain a sound alloy capable equally of being cast, forged, and machined it is advantageous to add 1 to 3 per cent. of manganese and from 0·2 to 0·4 per cent. of carbon, but any chromium addition is useless, as at liquid air temperatures pure, or slightly manganiferous, alloys have the required limit of elasticity. Such an alloy should contain from 55 to 60 per cent. of nickel, and is, further, practically non-oxidising.

R. R. Moore, *Elastic Properties of Thin Wire Ropes* (Mechanical Engineering, February 1922, vol. 44, pp. 105–106). The results of tensile tests on wire ropes with varying numbers of strands of wire of a given composition are recorded.

E. A. Fessenden, *Tests on Welded Cylinders* (Mechanical Engineering, September 1922, vol. 44, pp. 581–586). In order to compare the methods of constructing cylinders for containing anhydrous ammonia, four types of construction were tested, namely, flange steel shell, with acetylene welded longitudinal seam and concave heads forge-welded to shell; seamless pipe shell, with convex head acetylene-welded to shell; seamless pipe shell with concave heads forge-welded to shell; and flange-steel shell, with acetylene-welded longitudinal seam and convex heads acetylene-welded to shell. The cylinders were all subjected to hydraulic tests. The vessels having forge-welded heads were the least reliable, and burnt steel was often found present in the weld. A common defect in acetylene welds is a coarse granular structure and occasional porous spots and pinholes that develop with high pressure. Some suggestions for the avoidance of these defects are made.

L. Jannin, *A New Method of Testing the Wearing Properties of Metals* (Revue de Métallurgie, Mémoires, February 1922, vol. 19, pp. 109–116). Flat specimens of metals are held at constant pressure against a steel cylinder rotating at constant speed, and the depth of the worn surface is measured, using a microscope similar to that used in determining Brinell hardness.

L. Guillet (Revue de Métallurgie, Mémoires, February 1922, vol. 19, pp. 117–119) substitutes a cylindrical piece for the flat one, and has tested the wearing properties of various anti-friction metals in contact with steel.

A. M. Cox, *The Abrasive Qualities of Plain Carbon and Alloy Steels*

(Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 680–690). The author gives the results of a series of tests carried out to determine the effect of various heat treatments on the abrasive qualities of steel. Four kinds of steel were used in the experiments, two plain carbon steels with 0·52 and 0·226 per cent. carbon respectively, and two chrome-nickel steels, one with 0·550 per cent. carbon, 1·84 per cent. nickel, and 0·990 per cent. chromium, and the other with 0·240 per cent. carbon, 1·490 per cent nickel, and 1·150 per cent chromium. The machine used is described. The results indicate that the greater the density and hardness, the greater the resistance to abrasion. The ordinary tension and Brinell tests are not a reliable index to the abrasive qualities of a material. The carbon steels showed more uniform results than the chrome-nickel steels and less average wear loss.

H. L. Whittemore and S. N. Petrenko, *Friction and Carrying Capacity of Ball and Roller Bearings* (United States Bureau of Standards, Technologic Paper, No. 201). An account is given of experiments to determine the maximum safe load and static friction under load of ball and flexible roller bearings.

E. Madsen, *Formulæ for Wave-Lengths of Corrugations and Axle Diameters* (Verkehrstechnik, December 15, 1921, pp. 543–546). The results of the author's investigations show that a properly proportioned axle-diameter is of the greatest importance in overcoming corrugation of rails, the causes of which are enumerated.

The Corrugation of Tramway Rails (Tramway and Railway World, September 14, 1922, vol. 52, pp. 126–129). A number of suggestions are advanced as to the causes of corrugation. The principal cause, or at least one of the main causes, of this irregular wear is the fact that the conditions of working are such that sliding of the surfaces in contact under very heavy pressure takes place, as well as pure rolling between them.

J. B. Johnson and S. Daniels, *Study of some Failures in Aircraft Plane and Engine Parts* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1167–1176, 1212). The paper contains a compilation of several investigations made by the Material Section of the Engineering Division Air Service, of breakages which have occurred in airplane and engine parts under service conditions.

British Standard Specification for Steel Girder Bridges (British Engineering Standards Association: Report 153, 1922). Part I. of this report covers the materials to be employed, which are required to be in accordance with one or other of the existing British standard specifications. Part II. deals with workmanship, including, amongst other items, clauses dealing with straightening, planing, and shearing, drilling, punching, and reaming, rivets and riveting, bolts and nuts, painting, measurement, and packing and marking for export.

Specification for Bull-Head Rails (British Engineering Standards

Association, Report 9, 1922). The present report is the second revision of the specification originally published in 1904. Two classes of steel are now included, namely, ordinary carbon and high-class carbon steel, and separate chemical analyses are specified for Bessemer and open-hearth steels. The range of ultimate tensile strength for ordinary carbon rails, namely, from 40 to 48 tons per square inch, has been increased from 42 to 53 tons per square inch, and a range of tensile strengths for higher carbon steels included 46 to 55 tons per square inch for acid or basic open-hearth steel, and from 44 to 53 tons per square inch for acid Bessemer steel.

British Standard Specification and Sections for Flat Bottom Railway Rails (British Engineering Standards Association, 1922, Report 11).

British Standard Dimensions for Long Sweep Type Malleable Iron Pipe Fittings for Steam, Water, and Gas (British Engineering Standards Association, 1922, Report 143).

British Standard Specification for Girder Bridges (British Engineering Standards Association, 1922, Report 153).

British Standard Dimensions for Malleable and Soft Cast Iron Pipe Fittings for Steam, Water, and Gas (British Engineering Standards Association, 1922, Report 154).

R. M. Bird, *Standardisation of Methods Leading to Comparative Physical Properties of Alloy Steels* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1213–1218). The standardisation of heat-treating operations necessary to give alloy steels the required physical properties for particular uses is discussed and the procedure adopted by the Bethlehem Steel Company is described.

A. W. F. Green, *The Annealing of Tool Steels* (Forging and Heat-Treating, August 1922, vol. 8, pp. 346–353). The factors which govern the success of the annealing operation are examined, namely, time, temperature, mass, surface, and the human element. Special attention is directed to the inseparable relationship existing between these factors.

L. A. Lanning, *Change of Volume of Tool-Steel on Heat-Treating* (Forging and Heat-Treating, December 1921, vol. 7, pp. 610–611). The samples used for the test were in the form of cylinders 3 inches long and $\frac{5}{8}$ inch diameter, cut from a single bar of annealed tool steel. The analysis of the steel was: carbon 1·10, manganese 0·30, phosphorus 0·02, sulphur 0·02. It was found that very rapid heating for hardening followed by a water-quench causes the piece to elongate, the amount of elongation decreasing as the heating time is increased, until a point is reached where no change in dimension occurs. It is concluded that there is a critical rate of heating for hardened high carbon steel where there is no change in dimension. When this critical heating rate is exceeded the steel elongates in a direction parallel to the rolling, and when the heating rate is slower than the critical rate the steel shortens along the same axis.

Increasing the quenching temperature increases the amount of change when there is a deviation from the critical heating rate.

When the steel is quenched in oil the rate of heating has little influence on dimension change and the steel shortens along the axis of rolling.

The original heating for hardening has a marked influence on the dimensional changes which take place on rehardening the same pieces.

Tempering shortens the elongated pieces, the effect increasing as the tempering temperature rises when the pieces are water-quenched, this shortening action being almost negligible in oil-hardened pieces.

M. A. Grossman, *The Change in Dimensions of High-Speed Steels in Heat Treatment* (Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 691–695). The author has studied the change in length of steel due to heat treatment. Three steels of the following composition were used in the experiments :

	Per Cent.	Per Cent.	Per Cent.
Carbon . . .	0·65	0·65	0·85
Tungsten . . .	18·00	15·00	13·00
Chromium . .	3·5	3·5	3·5
Vanadium. . .	1·0	0·5	0·50

The length of the test-pieces was measured in the annealed condition as prepared, then in the quenched condition after hardening, and then after drawing at various temperatures. The results show that high-speed steels of this type always expand in hardening. In general, up to a certain limit, the higher the hardening temperature the greater will be the expansion. When this hardened steel is drawn, it contracts at temperatures up to 900° to 1000° F. When heated at 1100° F. it expands and when finally heated at higher temperatures it contracts until it finally reaches approximately the original dimensions of the annealed condition. A comparison of the three steels shows that the first expansion is greater in the lower tungsten steels, and that the second expansion, namely at 1100° F., is greater in the higher tungsten steels. A further important point is that, while the lower tungsten steels can be heat-treated to develop a reasonably large amount of austenite, the heating in the highest ranges causes overheating, coarse grain, and its accompanying brittleness. The higher tungsten steels can be heated to temperatures high enough to develop a very considerable amount of austenite and still retain a fine-grained structure.

M. A. Grossman, *Shrinkage and Expansion of High-Speed Steel due to Heat Treatment* (Chemical and Metallurgical Engineering, September 13, 1922, vol. 27, pp. 541–544). Tests were carried out on a steel containing 0·65 per cent. of carbon, 18 per cent. of tungsten, 4 per cent. of chromium, and 1 per cent. of vanadium, cylinders $1\frac{1}{2}$ inch in diameter and $2\frac{1}{2}$ inches long, being heat-treated and changes in length noted. They showed that, apart from the quenching temperatures, there is a certain regular trend of the contractions and expansions on reheating which in general vary in amplitude but not in direction. Shrinkage curves offer as yet no evidence as to the composition of the phases taking part in these reactions, but with improvements in the methods such evidence may, it is hoped, be forthcoming. Hardness and microscopic examination tests were used to supplement the results. Volume changes resulting from heat treatments may be due (1) to expansion taking place during the transformation from austenite to martensite, and (2) to the contraction occurring after heating martensite, assumed to be due to the formation of carbide molecules and crystals from elemental iron and carbon. The evidence derived from the structural changes is adduced in support of the theoretical explanation of the observed volume changes in the steel under discussion.

M. A. Grossman, *The Toughness of High-Speed Steels as Affected by their Heat Treatment* (Transactions of the American Society for Steel Treating, August 1922, vol. 2, pp. 1001–1005). The author gives the results of toughness tests on two high-speed steels of 18 and 13 per cent. tungsten respectively. The tests were carried out on a Charpy impact machine on unnotched specimens. It was found that there is a certain quenching temperature slightly below the proper hardening range for which the steel is brittle on being quenched and acquires no toughness on being drawn up to 1100° F. Below this quenching range, drawing imparts toughness but lowers the hardness. Above that range, drawing at 1100° imparts toughness while at the same time developing secondary hardness. Curves are given showing the changes in toughness for the different heat treatments and the change in scleroscope hardness for those heat treatments.

J. V. Emmons, *The Effect of Structure upon the Machining of Tool Steel* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1100–1110, 1212). Detailed observations are made of the effect of the various structural constituents upon the machinability of tool steel. The machining operations considered are turning, milling, drilling, reaming, thread cutting, swaging, wire-drawing, punching, and shearing. General conclusions are drawn as to the most favourable structures for the various machining operations. Explanations of many of the difficulties encountered are offered, and suggestions are made for the development of annealing processes to secure the desired machinability.

A. W. F. Green, *Black Fractures in Carbon Tool Steels* (Chemical and Metallurgical Engineering, August 9, 1922, vol. 27, pp. 265–267). The appearance in question has been noted only in hypereutectoid steel made by the crucible process, and only in straight carbon tool steel. It is seen by the unaided eye as a mossy, solid black constituent. It occurs after annealing, in circumstances where complete spheroidisation of the cementite in the unaffected areas has taken place, that is to say, in structural conditions which are considered as most desirable in carbon tool steels. Chemical analysis reveals no difference between the black areas and the rest of the metal, but they are much softer than the remaining areas (Brinell 95 as against 170), Experiments appeared to suggest that low temperature annealing favoured the occurrence of these spots, but no explanation of their nature or ultimate cause is so far forthcoming.

J. V. Emmons, J. A. Mathews, and C. M. Johnson comment on this article (Chemical and Metallurgical Engineering, September 6, 1922, vol. 27, pp. 484–485). The two former ascribe the appearances to the precipitation of graphitic carbon from cementite, due to prolonged annealing, and to temper carbon, appearing as the result of bad mill practice respectively. C. M. Johnson draws attention to the presence of high silicon in steels showing black fractures and suggests that the carbon is precipitated owing to the high silicon content. The presence of two or three tenths of a percentage of chromium deters the formation of graphite and manganese is said to do the same.

H. S. Rawdon and S. Epstein, *Graphitisation in a Carbon Tool Steel* (Chemical and Metallurgical Engineering, September 27, 1922, vol. 27, pp. 650–651). A description, with photomicrographs, of the phenomenon of graphitisation in a tool steel. The well-defined zones found had a different distribution of carbon, the carbon having, after heat treatment, reverted from the graphitic to the combined form.

A. H. d'Arcambal, *Physical Tests on High-Speed Steels* (Iron Age, July 6, 1922, vol. 110, pp. 1–5). The results of transverse and tensile tests of two grades of high-speed steel are compared and the effect of these properties on the service of the tool are discussed.

H. J. French and J. Strauss, *Lathe Breakdown Tests on Some Modern High-Speed Tool Steels* (Transactions of the American Society for Steel Treating, September 1922, vol. 2, pp. 1125–1154). A comparison is made of the performance of modern high-speed tool steels in the so-called lathe breakdown tests in which the endurance of tools is measured under definite working conditions. The limitations of this method when applied to the purchase of steel are pointed out. It is concluded that breakdown tests are not satisfactory as the basis of purchase for high-speed steels. While competitive comparisons of brands of nearly similar performance are not justified owing to the qualitative nature of this type of test, relatively large differences may be ascertained with certainty providing sufficient tools are tested and averages of at least two grinds are used in the interpretation of results. In certain severe breakdown tests with roughing tools on 3 per cent. nickel steel forgings, in which high frictional temperatures were produced, it was found that the performance of commercial low tungsten, high vanadium, and cobalt steel was superior to that of the high tungsten, low vanadium type and special steel containing about 0·25 per cent. uranium and 0·75 per cent. molybdenum. Modification in test conditions, including changes in tool angles but principally changes in cutting speed, more markedly affected the performance of steel containing cobalt or special elements such as uranium or molybdenum than that of the plain chromium-tungsten-vanadium steels. The relatively poor endurance of the high tungsten steels under severe working conditions was not observed in more moderate tests. Hardness determinations and examination of fractures indicate that the various types of commercial high-speed steel show differences in behaviour under heat treatment and in physical properties which probably are of importance under moderate working conditions, and might counterbalance slight advantages in performance.

H. K. Ogilvie, *Practical Notes on the Manufacture and Treatment of High-Speed Steel.* (This Journal, p. 155.)

J. W. Weitzenkorn, *Notes on the Manufacture of High-Speed and Tungsten Steels* (Chemical and Metallurgical Engineering, March 15, 1922, vol. 26, pp. 504–508). The author traces the steps taken in studying segregation in high-speed and tungsten steel. Massive carbides were separated from high-speed steel, analysed, and found to approximate to the composition of the ferro-tungsten used in their manufacture. The structural deposition of these carbides after various heat treatments has been studied, with or without previous mechanical work, and the conclusions are summarised as follows: The composition of the eutectiform carbide examined may be represented by the formula $VCr_2W_{10}Fe_{22}C_9$ and has the following chemical composition: carbon 3·10, tungsten 55·90, chromium 3·31, vanadium 1·52, iron 36·17 per cent., and excepting for the chromium and vanadium content is the approximate composition of ferro-tungsten. The composition of the primary austenite of the specimens examined appears to be: carbon 0·77, chromium 3·10, vanadium 0·63, tungsten 3·71 per cent. These eutectiform carbides are essential factors in imparting high-speed properties. When present in eutectiform mass, these carbides produce in high-speed steel a coarse, fibrous, woody fracture in the annealed, natural, or hardened states. This condition causes the steel to be difficult to anneal, to possess hard and soft spots after annealing, to tear and show bright streaks on machining, to be brittle or short even in the annealed condition, to develop cracks in hardening, and to lower the cutting efficiency. This condition is favoured by high casting temperature and slow cooling, hence the advisability of using ferro-tungsten with its lower melting point and easy solution in the melting mass of the charge, which form of tungsten favours lower temperatures, more rapid melting, and quicker cooling. This condition can be broken up best by the combination of heat and sufficient mechanical work. It cannot be entirely removed by heat alone, nor eliminated by hardening or annealing.

Treatment and Behaviour of Drill Steel (Mining Journal, July 8, 1922, vol. 138, pp. 523–524). A resumé is given of a report to the U.S. Bureau of Mines and the Bureau of Standards on the breakage and heat treatment of rock drill steels. Information has been collected as to the hardening and heat treating of drills at a number of mines.

W. J. Merten, *Hardness and Cutting Qualities of Hypoeutectic, Eutectoid, and Hypereutectic Steels for Reamers and other Cutting Tools* (Forging and Heat-Treating, June 1922, vol. 8, pp. 284–286). Describes the properties, constitution, structure, and treatment of carbon steels to render them serviceable as cutting tools.

E. G. Coker and K. C. Chakko, *An Account of some Experiments on the Action of Cutting Tools* (Proceedings of the Institution of Mechanical Engineers, 1922, vol. 1, pp. 567–621). The paper describes an investigation of the action of cutting tools by the aid of polarised light.

F. Lepersonne, *Note on Molybdenum Steels* (Revue Universelle des Mines, January 15, 1922, vol. 12, Series 6, pp. 159–165). Gives a summary and a short bibliography embodying the latest views as to molybdenum steels. A note is given of the occurrence of the ores and the market prices of the metal. A diagram of the carbon-molybdenum system is also given, and the physical properties and heat treatment of molybdenum steels are described, including a table of Izod values. The conditions under which such steels are workable, hot and cold, are also noted.

H. J. French, *Effect of Heat Treatment on Mechanical Properties of a Carbon-Molybdenum and a Chromium-Molybdenum Steel* (Transactions of the American Society for Steel Treating, June 1922, vol. 2, pp. 769–798). The thermal transformations of a carbon molybdenum steel containing 0·20 per cent. carbon and about 1 per cent. molybdenum and a chromium-molybdenum steel with 0·27 per cent. carbon, 0·9 per cent. chromium, and 0·5 per cent. molybdenum are given for various temperatures of heating and rates of cooling. The effect of variations in normalising temperatures, variations in temperature from which the steels are hardened, and the effects of tempering at various temperatures on the mechanical properties and structure of these steels are discussed. Comparison of various methods of heat treatment for the production of definite tensile strength and impact values in the carbon-molybdenum steel are also given.

H. Chandler, *The Steel Requirements of the Automotive Industry* (Paper read before American Iron and Steel Institute, October 27, 1922). The properties essential in certain classes of steel to meet service conditions are determined, the tests used to determine the requisite mechanical properties are described, and some notes on heat-treatment are given.

J. H. Hall, *Pearlitic and Sorbitic Manganese Steels* (Iron Age, September 28, 1922, vol. 110, pp. 786–788). The author contends that a manganese content of 1 per cent. or a little above has a beneficial effect on low carbon steel, and quotes the work of previous investigators in support of this.

Vanadium and its Metallurgical Uses (Engineering, August 4, 1922, vol. 114, pp. 150–151). A short review of the sources of vanadium, its extraction from the ores, its preparations and uses in alloying with steel, and its influence on the mechanical properties.

Uranium and its Uses in Metallurgy (Revista Minera, May 8, 1922, vol. 73, pp. 268–269). Of all known metals, uranium has the greatest atomic weight, namely 239, the specific weight being 18·7. It has a melting point of 1800°, and volatilises more rapidly than iron. The principal occurrences of uranium are in the Joachimsthal in the Ore Mountains, at Annaberg in Saxony, and in some localities in the United States. The total output of uranium in 1917 and 1918 was 87·4 tons and 98·5 tons respectively, with 26·4 and 27·1 grammes of radium. Apart from its employment as a source of its associated radium, uranium is mainly used as an addition to steel.

Magnetic Properties of Iron and Steel.—E. D. Campbell and E. R. Johnson, *A Preliminary Magnetic Study of Some Heat-Treated Carbon Steels.* (This Journal, p. 201.)

E. Maurer and F. Meissner, *A Simple Form of Bar for Determining the Magnetic Properties by Means of the Ballistic Method* (Mitteilungen a. d. Kaiser-Wilhelm-Institut für Eisenforschung, 1922, vol. 3, No. 2, pp. 23–27). It is shown by means of experiments that bars of cylindrical form do not give satisfactory results when using the ballistic method for coercive force and remanence of carbon steels and alloy steels. By the adoption of a bar having approximately an ellipsoidal form, which it is easily within the resources of an ordinary workshop to fashion, the difficulty was overcome and much more accurate measurements are possible.

S. Fukuta, *On the Effect of Longitudinal Stress on the Electrical Resistance of Carbon Steels* (Science Reports of the Tohoku Imperial University, Sendai, May 1922, vol. 11, pp. 131–137). Experiments were carried out in an Olsen testing machine on Swedish carbon steels to determine the relation between electric resistance and stretching force. The results show that the increase of specific resistance is almost proportional to the applied stress, and that the increase of specific resistance slightly decreases with the increase of carbon content.

L. W. Wild, *The Influence of Heat Treatment upon the Magnetic Properties of Steel* (Transactions of the American Society for Steel Treating, May 1922, vol. 2, pp. 696–704). The author has confined his experiments to the measurement of intensity of magnetisation and coercive force, the two tests being carried out on the same set of specimens, the object being to obtain a general survey of the effects of reheating hardened steel to various temperatures and slowly cooling it. Experiments were carried out on Swedish charcoal iron, mild steel, carbon steel, tungsten, chrome, and nickel steels. The saturation intensity of the iron remains unaffected by heat treatment, though the coercive force declines as soon as hardening strains are taken out, and still further as grain growth commences. The most noticeable feature of the carbon steels is the rise of magnetic intensity between 200° and 300° C. when cementite is precipitated from solution. On reheating to a temperature of 400° to 800° C. apparently some of the cementite returns into solution, and does not entirely reprecipitate with slow cooling. On reheating to 1000° C. or more when all cementite must be in solution, apparently all precipitates on slow cooling. A very large drop in coercive force takes place in the carbon steels between 200° and 300° C. which is probably due to the cementite coming out of solution and then becoming magnetic. The rise of coercive force at 500° C. may be due to the cementite again partially entering solution and not precipitating on cooling. The nickel steel behaves in very much the same way as carbon steel. The nickel, however, which, when in a free state, is only about one-third as magnetic as iron, becomes about equivalent to iron when alloyed with it. The tungsten steel follows the general line of a carbon steel except that the carbon features are less pronounced, and there is a decided drop of magnetic intensity and increase of coercive force when a reheating temperature of 900° C. is exceeded. The chromium steel, although containing 87 per cent. of iron, has a saturation intensity of about 67 per cent. of pure iron, and this remains almost entirely unchanged by heat treatment. The coercive force does not drop, on tempering, nearly so steeply as with other steels, and the rise on heating to over 900° C. is even more pronounced than with tungsten steels.

K. Kido, *Magnetic Researches of Nitrogenised Steels* (Science Reports of the Tohoku Imperial University, 1922, vol. 10, pp. 471–478). Ten samples of steel containing from 0·084 to 3·02 per cent. of carbon were pulverised and then nitrogenised by heating in a current of dry ammonia gas at 650° C. for periods varying from five minutes to fifteen hours. After treatment the surface of the steel varied in colour from silver grey to dark grey, according to the duration of nitrogenisation. The samples were then submitted to magnetic analysis. It was observed from the change of intensity of magnetisation with temperature that four transformations were possible at 250°, 350°, 470°, and 620° C. respectively, the actual number of these transformations taking place in any given sample depending upon the composition. The magnetic transformation at 250° C. is due to the compound Fe_2N, that at 470° C. to $Fe_{12}N$, whilst the transformations at 350° C. and 620° C. are attributed to two double carbides of iron and nitrogen termed α and β respectively. On heating to 700° C. the nitrides of iron are rapidly decomposed into nitrogen and ferrite, the gaseous nitrogen escaping.

F. Wever, *The Arrangement of the Atoms in Magnetic and Non-Magnetic Nickel* (Mitteilungen a. d. Kaiser-Wilhelm-Institut für Eisenforschung, 1922, vol. 3, No. 2, pp. 17–22). The arrangement of the atoms of α-nickel was radiographically examined, in various specimens of pure nickel, and of commercial nickel containing a moderate amount of impurities. The former investigations of Hull, according to which nickel at ordinary temperature shows two forms of crystals with different space lattices, were not confirmed. The atomic arrangement is uniformly a cubic surface centred lattice with a parameter of $3{\cdot}51_9 \times 10^{-8}$ centimetres. The impurities tend to increase the distance between the atoms. The similarity of the magnetic transformation of nickel with that of iron is again confirmed. It is shown that β-nickel, like β-iron, cannot be regarded as an allotropic form.

Heat-Treatment, Metallography, Crystallography.—A. Portevin, *Experimental Contribution to the Study of Hardening Cracks in Shells* (Revue de Métallurgie, Mémoires, May 1922, vol. 19, pp. 267–295). In the first place Brinell hardness tests were carried out on all shells that had shown hardening cracks. In all, practically, it was found that the hardness varied considerably in different parts of the projectile. Diagrams were then plotted showing the relation of the positions of the flaws to the areas of irregular hardness. These appeared to indicate that the cracks occurred exclusively in hard zones, and followed the boundaries with the softer zones. The conclusion is irresistible that such cracks are due, first and foremost, to irregularities in quenching, apart from all questions as to the nature of the steel, or other modes of treatment to which it may have been subjected. A series of experiments was therefore planned and carried out on the artificial production of such cracks, by methods of irregular cooling during hardening, and an account of these experiments and of their results is given. In this connection it is pointed out that the belief usually held that the hydraulic test is intended to reveal the presence of cracks is incorrect, the object really being to ascertain if the elastic limit of the walls of the projectile is sufficiently high to ensure a suitable disruption under the pressure of the expanding gases. In such cases the strains act differently according as they are effected longitudinally or transversely. There is no doubt that the composition of the steel has an important influence, but the main cause of cracks is irregular cooling.

L. Guillet, *The Phenomena of Hardening and Generalisations thereon* (Chimie et Industrie, February 1922, vol. 7, pp. 211–225). A review, illustrated by diagrams and photomicrographs, of existing knowledge on the phenomena of quenching and hardening. Evidence is brought forward showing that whether the metals concerned are iron alloys or alloys of copper or aluminium, the phenomena are invariably of the same character and consist broadly in the complete or partial solution of the constituents stable at ordinary temperatures, brought about by quenching, and by the precipitation of these constituents on annealing, this precipitation causing a considerable increase in tensile strength and hardness, due no doubt to the finely divided nature of the material structures.

L. Guillet, *The Tempering Phenomena and their Generalisation*

(Chimie et Industrie, February 1922, vol. 7, pp. 211–225). A general article discussing the critical points in heating and cooling curves and the structural changes in steel due to quenching from different temperatures.

P. D. Merica, *A Discussion of the Slip Interference Theory of Hardening* (Chemical and Metallurgical Engineering, May 10, 1922, vol. 26, pp. 881–884). Hardness caused by dispersed particles is due to a dislocation in the spacing of surrounding atoms rather than to intrinsic hardness of particles themselves. Maximum hardness does not involve minimum ductility. Extreme cold-work actually causes a slight softening.

G. Charpy and L. Grenet, *Penetration of Hardening Effect in Steel due to Quenching* (Comptes Rendus, 1922, vol. 174, pp. 1273–1276). Square bars of steel of different quality were heated in a furnace, and were held at 800° until they were of uniform temperature throughout. The upper part of the bars were then wrapped in asbestos and a stream of cold water was directed on the extreme end of the exposed part. When the bar was completely cooled the hardness was determined on one side at different distances from the base. The hardness values obtained agree with those obtained on a piece cut out from a thick steel block after quenching. With a nickel-chrome steel quenched after heating to 800° the Brinell hardness varied from 387 at a distance of 3 millimetres from the end of the bar to 180 at 90 millimetres distance. In a self-hardening steel, quenched from 800°, the hardness was practically uniform along the whole length of the bar.

A. Poucholle, *Contribution to the Study of Quenching* (Comptes Rendus, February 27, 1922, vol. 174, pp. 611–613). A steel wire of eutectoid composition, 1 millimetre in diameter and 1 metre long, was heated, and the changes in length were studied during cooling in air. The cooling was rapid enough to be regarded as quenching, and the Ar1 point occurred at a comparatively low temperature; mechanical stress began to be set up in the range of temperature between 650° and 200° C. The range of temperature in which Ar1 occurs is reduced by increasing the temperature to which the wire is heated before cooling, by prolonging the period of heating.

C. R. Hayward, D. M. MacNeil, and R. L. Presbrey, *Effect of Time in Reheating Quenched Medium-Carbon Steel below the Critical Range* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, vol. 67, pp. 82–86). The heat treatment was carried out in a small electric resistance furnace. The steel used contained 0·46, 0·44, and 0·48 per cent. of carbon. The results of the experiments show that even five minutes' heating of the quenched steel at 300° C. lowers considerably the strength and hardness and increases the ductility. There is a marked increase in ductility in passing from the 400° to the 500° treatment without an equivalent lowering of strength; it is accompanied, however, by a change from indefinite to a definite yield point. This was clear on the original load-elongation curves. Although the annealed specimens from the three bars showed the same yield point and ultimate strength, there was a difference in the ductility; this explains the drop in ductility between the half hour and one hour treatment at 600°. The specimens reheated to 600° C. are nearly as ductile as the annealed specimens, but they have an elastic limit about 60 per cent. greater. In spite of several irregularities in the curves, it is evident that reheating the steel for one hour is all that is necessary, and there are indications that for temperatures of 400° and below half an hour is sufficient.

C. H. Desch, *The Work of Sorby and the Development of Metallography* (Journal of the West of Scotland Iron and Steel Institute, Session 1921–1922, vol. 29, pp. 62–71).

L. Guillet, *Recent Progress in Microscopic Metallography and in Macrography* (Liége Scientific Congress, 1922; Metallurgical Section, pp. 1–17; Revue Universelle des Mines, July 1922, vol. 14, Series 6, pp. 7–23). The progress of metallography is considered from the point of view of the methods of preparing and examining the samples, polishing, etching, examination and photographing, and from that of the interpretation and application of the results. Amongst the etching and staining reagents recently introduced is Yatsevitch's reagent for staining the carbides in tool steels, and consisting of 10 per cent. sodium hydroxide solution diluted with half its volume of oxygenated water, and Ingall's reagent, which is used for zinc etching. Recent progress in methods of macroscopic examination is also reviewed.

C. Benedicks, *On Beilby's Theory of the Amorphous State of Metals* (Revue de Métallurgie, Mémoires, August 1922, vol. 19, pp. 505–513). A detailed review and critique of the work of Sir George Beilby on the flow of solids; dealing, in its critical aspect, more particularly with the theory of amorphous states. The view that surface colours are due to thin layers of amorphous substances in a plastic state is not borne out by metallographic facts, and renders the whole theory challengeable. The views as to the cause of hardness are also contested, and Benedicks' own theory of stress hardening proposed as an alternative based on facts more in accordance with known phenomena.

H. A. Schwartz, H. R. Payne, A. F. Gorton, and M. M. Austin, *Conditions of Stable Equilibrium in Iron Carbon Alloys* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, No. 1181–S). As the result of investigations, the nature of which is described, the conclusion is arrived at that the solid solution of the stable system is distinct in structure, electrical properties, and temperature-solubility relations from those of the metastable system. For the new stable solid solution the name boydenite is proposed. As it differs from austenite of equal carbon concentration in every measurable characteristic, they cannot both be solid solutions of either cementite or carbon. The logical conclusion is that austenite is a solution of cementite and boydenite a solution of carbon. A stable and metastable equilibrium diagram for hypoeutectoid carbon-iron alloys containing ± 1 per cent. of silicon is propounded.

A. Fry, *Etching to Develop Overstrain* (Chemical and Metallurgical Engineering, August 23, 1922, vol. 27, p. 349). A translation is published of the author's paper (Stahl und Eisen, August 11, 1921, vol. 41, pp. 1093–1097) describing his new etching process. It brings out markings in overstrained steel which bear a close relationship to the lines of maximum shear as determined mathematically. The usual preliminary operations are carried out, care being taken to avoid deformation during grinding and polishing. The specimens are then reheated for about half an hour at 200° C. The etching medium is 40 cubic centimetres of concentrated hydrochloric acid, 30 cubic centimetres of water, 25 cubic centimetres of ethyl alcohol, and 5 grammes of cupric chloride crystals. A separate solution much stronger in cupric chloride is used for macro etching. After immersion the specimen is rubbed with finely pulverised cupric chloride on a rag moistened with the etching solution until the desired contrast is obtained, dried without rinsing, washed with alcohol, and again dried. The solutions being strongly acid do not deposit copper. The etched pattern of dark and light bands is said to owe its dark portions to the presence of iron hydride, and these portions indicate the amount of plastic deformation the metal has received.

B. Strauss and A. Fry, *Formation of Cracks in Boiler Plates* (Forging and Heat-Treating, May 1922, vol. 8, pp. 225–229). A translation in full is published of the paper by these authors describing an investigation of boiler plates by the aid of a new etching medium (see *Stahl und Eisen*, August 11, 18, 1921, vol. 41, pp. 1093–1097, 1133–1137). The metallographic illustrations are reproduced.

P. Dejean, *Methods and Appliances Employed for the Determination of Critical Points* (Liége Scientific Congress, 1922, Metallurgical Section, pp. 19–47; Revue Universelle des Mines, August 15, 1922, vol. 14, Series 6, pp. 265–293). A very full account of the determination of critical points and of the apparatus used, including a definition of the points sought, and a discussion of their ascertainment by specific heat, dilatation, magnetometric, electrical resistance, thermo-electric and mechanical means. The methods of plotting the usual heating and cooling curves, and practically every type of recording apparatus used are illustrated and described. They include Rengade, Coste, Portevin and Garvin, Chevenard, Leeds-Northrup, Gueugnon, Wologdine, Pellin, Saladin, Le Chatelier-Saladin and Le Chatelier-Broniewski recorders and pyrometric and dilatometric apparatus.

P. Chevenard, *New Applications of Dilato-Pyrometric Methods to the Thermal Analyses of Alloys* (Liége Scientific Congress, 1922, Metallurgical Section, pp. 49–68; Revue Universelle des Mines, September 1, 1922, pp. 351–370). Both the differential pyrometer and the galvano pyrometer serve to check methods of manufacture, but their main service is in the investigation of the properties of alloys. By using pyros and fused silica a strong, serviceable, and accurate dilatational pyrometer can be made available for such investigations, the nature and applications of which are described.

J. H. Whiteley, *The Diminution of Lag at* Ar1 *through Deformation.* (This Journal, p. 89.)

J. F. Shadgen, *Heat Temperature Curves of Metals* (Iron Age, July 27, 1922, vol. 110, pp. 218–222). The result of the work of Wüst, Meuthen, and Dürrer on the heat constant temperature curves is given at length.

H. Jungbluth, *The Characteristic Curves of a Nickel Steel and a Chromium Steel* (Stahl und Eisen, September 7, 1922, vol. 42, pp. 1392–1396). The author has carried out experiments based on the work of Portevin and Chevenard (*Journal of the Iron and Steel Institute*, 1921, No. II. pp. 117–140) showing the influence of the temperature of heating and rate of cooling on the properties of a steel of given chemical composition. A 5 per cent. nickel steel with 0·5 per cent. carbon, and a steel with 1·6 per cent. chromium and 1·6 per cent. carbon were used by the author. Portevin and Chevenard, in plotting their curves of equal hardness, took as ordinates the rate of cooling in degrees per second, and as abscissæ the quenching temperature. Jungbluth now plots curves of equal hardness, taking the rate of cooling in minutes as ordinates and the quenching temperatures as abscissæ. It is shown that the characteristic curves thus obtained do not continue their upward course, but bend round as the region of superhardness is reached.

G. Tammann, *The Transformation of Cementite at* 210° (Stahl und Eisen, May 18, 1922, vol. 42, pp. 772–775). Certain properties of carbon steels, consisting of two types of crystals, ferrite and cementite, though they vary according to the composition of the crystals, are not represented by a straight line curve, but by two straight lines which intersect one another at the point of the pearlite composition. Diagrams show the dependence of heat content, of the electric resistance, and of the coercive force on the carbon percentage, and in each case the plotted curve is formed of two straight lines. This indicates that the pearlitic cementite cannot be identical with the primary cementite which separated from the γ-iron and the molten mass. They are probably two different types of crystal of similar composition, or their properties may differ in respect of grain size.

The discovery by Honda and Takagi of a transformation point of cementite at 210° makes it possible to elucidate this point. For if the pearlitic cementite and the primary are the same crystal types, they must have the same transformation point; otherwise the temperature of their transformation points will not be the same. By means of a magnetic investigation, it is proved that the type of crystal is the same for the pearlitic as for the primary cementite, and the variation in the properties as the carbon content varies is due to the difference in the grain size of the cementite.

H. C. Ihsen, *Spheroidising of Cementite in Steel* (Forging and Heat-Treating, July 1922, vol. 8, pp. 300–303). The results of the tensile tests reveal a very striking increase in ductility when the steel is in the spheroidised condition. The percentage of reduction of area is a much better measure of the shock-resisting properties of the material than any other of the values shown in the standard tensile test. In the tests of the material showing a completely pearlitic structure the reduction of area is about 6 per cent.; in the material showing a structure only partly spheroidised the reduction of area ranges from 10 to 11 per cent.; while in the material showing a completely spheroidised structure the reduction of area ranges from 19 to 26 per cent. The ultimate tensile strength is slightly lower in the steel showing a spheroidised structure while the elastic limit remains about the same. The percentage of elongation follows closely the percentage reduction of area. Also these tests show that a long time anneal at or just below the thermal critical range is not necessary to obtain the spheroidised structure, provided that the material has received the proper preliminary treatment. Before the spheroidising treatment, the material should be heated above the Ac_{cm} thermal critical range and cooled as rapidly as possible, then reheated to just above the lower critical range and again cooled as rapidly as possible.

In these tests a completely spheroidised structure was obtained after both oil and air preliminary quenching, but the physical tests showed better properties when preliminary oil quenching was used, indicating that the more rapid the quenching the better the results to be expected from the spheroidising treatment.

P. Oberhoffer, *Influence of the Rate of Solidification of the Double Carbide Steels* (Stahl und Eisen, August 10, 1922, vol. 42, pp. 1240–1242). In order to determine the effect of the rate of solidification on the size of the eutectic network of steels containing varying percentages of carbon and chromium, and incidentally upon the final structure after working, and on the mechanical properties, tests were made by melting such steels in a crucible, and allowing them to cool alternatively in the crucible or pouring the charge into a cast iron ingot mould. Twelve charges were melted altogether, the carbon varying from 0·65 to 1·5 per cent. and the chromium from 1·9 to 13·45 per cent. The steels cooled in the crucible showed a dendritic structure with a coarse network, while those poured into the mould had a very fine globular structure with a fine network. The test-pieces were then forged down from 43 millimetres to 15 millimetres square, after which the slowly cooled steel still showed the network in its typical form, though in long drawn out threads, whereas the quickly cooled steel gave no indication of the eutectic and the carbide was very evenly divided. The tensile strength and hardness showed no marked difference, but the notch toughness was higher without exception in the quickly cooled steels.

H. Scott, *The Decomposition of Martensite into Troostite in Alloy*

Steels (Report of U.S. Bureau of Standards: Forging and Heat-Treating, July 1922, vol. 8, pp. 296–299). The effect of the alloying elements, manganese, silicon, nickel, cobalt, tungsten, chromium, vanadium, and molybdenum, on the decomposition of martensite to troosite was determined by means of heating curves. Only three of these elements showed a marked effect, namely, manganese, silicon, and chromium. The first-named increased the intensity of the transformation, while the last two raised its temperature when present in certain percentages. None of the alloying elements lowered the transformation, and no general relation was found to exist between it and the higher critical point Ac1. The significance of these data in regard to the heat treatment and properties of alloy steels is discussed.

A. E. Bellis, *Influence of Heating Medium on the Structural Changes in Steel* (Transactions of American Society for Steel Treating, February 1922, pp. 398–401). Gives an analysis of the changes in structure as influenced by heating and cooling media.

Z. Jeffries and R. S. Archer, *Grain Growth and Recrystallisation in Metals* (Chemical and Metallurgical Engineering, March 8, 1922, vol. 26, pp. 449–457). The authors put forward a conception of the fundamental causes of grain growth consistent with the observed facts and with modern developments in molecular physics. Crystalline nuclei are formed only on the appearance of a new crystalline phase. They may grow by the absorption not only of the disappearing phase but also of each other, so that the final number of grains may be less than the total number of nuclei formed. Grain growth results from the tendency of metals to assume the form of greatest possible physical stability. The principal conditions conducive to grain growth are small grain size and grain size contrast. Grain growth is opposed by mechanical obstruction and by inertia due to low temperature. A condition of metastability as regards grain growth must be recognised in which, while the metal is not in the most stable form, the forces tending to cause grain growth are insufficient to overcome the opposition to growth. As the temperature rises, this condition of apparent equilibrium approaches that of maximum stability. Recrystallisation is essentially grain growth on a submicroscopic scale. Germination consists in the preferential growth of certain grains favoured by their large size. The necessary condition is the existence of grain size contrast and suitable temperature such that the larger grains can grow at a considerably more rapid rate than the smaller grains. There is a critical amount of mechanical obstruction which favours the establishment of this necessary difference in growth velocity and hence germination.

P. Oberhoffer and H. Jungbluth, *The Recrystallisation of Commercial Iron* (Stahl und Eisen, October 5, 1922, vol. 42, pp. 1513–1519). The experiments confirm the results of Sherry (Iron Age, July 13, 1916, vol. 98, p. 76), showing that the maximum grain size results after a reduction of 10 per cent. in length by cold crushing and annealing at

700° to 800°. With an initial size of 800–1000 μ^2, after cold crushing to 10 per cent. and annealing at 700°, the grain size rose to about 14,000, and at 800° to 17,000 μ^2. On further crushing and annealing the grain size rapidly falls to its original size. It did not appear that any relation existed between pearlite formation and recrystallisation.

H. Alterthum, *The Theory of Recrystallisation* (Zeitschrift für Elektrochemie, August 1, 1922, vol. 28, pp. 347–356). According to the conception of the author the formation of grains and grain growth are the result of thermodynamic instability. It is shown that the energy changes which accompany the cold-working of a metallic crystal may be divided into reversible and irreversible changes, and the different degrees of working can be regarded as a continuous series of different modifications.

V. M. Goldschmidt, *Crystallography and Lattice Structure of Metals* (Zeitschrift für Metallkunde, October 1921, vol. 13, pp. 449–455). Five types of lattice in various metals are distinguished.

M. Born, *Thermodynamics of Crystal Lattices* (Zeitschrift für Physik, 1921, vol. 7, pp. 217–248).

W. Gerlach and O. Pauli, *The Crystal Lattice of Magnesium Oxide* (Zeitschrift für Physik, 1921, vol. 7, pp. 116–123).

R. Ledrus, *The Spectra of X-Rays* (Revue Universelle des Mines, January 15, 1922, vol. 12, Series 6, pp. 167–174; February 15, 1922, pp. 353–359, and March 1, 1922, pp. 444–447). The application of X-rays to the examination of the constitution of crystal structures is described, with diagrams and elementary formulæ. A resumé is given of the work of the leading investigators and the phenomena of X-ray absorption are discussed.

E. C. Bain, *X-Ray Data on Martensite formed Spontaneously from Austenite* (Chemical and Metallurgical Engineering, March 22, 1922, vol. 26, pp. 543–545). The author presents an interesting case in which coarse-grained austenite, after fifteen months at room temperature, is found unchanged in general appearance, but has become very hard and magnetic—in fact martensitic. Its X-ray spectrogram is that characteristic of very fine-grained ferrite.

W. Campbell, *Preparation of Metal for Microscopic Examination* (Chemical and Metallurgical Engineering, June 21, 1922, vol. 26, pp. 1163–1164). The preparation of specimens and the methods of etching are described.

E. D. Eastman, *Equilibria in the Systems Iron-Carbon-Oxygen and Iron-Hydrogen-Oxygen, and the Free Energies of the Oxides of Iron* (Journal of the American Chemical Society, May 1922, vol. 44, pp. 975–998). The author attempts to appraise and interpret the widely scattered and often discordant data relating to the oxides of iron and equilibria in which they are involved. The essential details of the more important researches are given.

E. Trasenster, *Graphic Representation of Binary Systems* (Liége Scientific Congress, 1922, Metallurgical Section, pp. 69–79; Revue

Universelle des Mines, September 1, 1922, vol. 14, Series 6, pp. 371–381). Plots a series of diagrams of condensed, and of multiple-constituent binary systems and describes their method of construction and the information to be derived from them. The leading types of resulting diagrams are classified as (1) temperature-pressure; (2) temperature-concentration; (3) calorie-concentration. The plotting of isothermal curves and the composition of conjugate phases are applied to the elucidation of the iron-carbon alloys.

E. Trasenster, *The Gaseous Phase and the Application of the Phase Rule to Alloys* (Revue Universelle des Mines, March 15, 1922, vol. 12, Series 6, pp. 483–491). After a brief enunciation of the four laws constituting the frame-work of the phase rule, the law of factors, the law of equivalence, the phase rule itself and the law of stability, it is pointed out that the law of equivalence and the phase rule play a part of preponderating importance in the theory of alloys. In some cases it happens that a chemical compound or a solid solution of constituents decomposes on heating, and as such a reaction occurs at a fixed temperature (the system being invariant) there will be, beside the gaseous phase, the decomposing phase and the two phases resulting therefrom of three solid or liquid phases. It is generally tacitly assumed that at atmospheric pressure the gaseous phase in metals is condensed and need not be counted. This is not always correct. Under atmospheric pressure the gaseous phase exists, diluted by that pressure and resulting from the vapour tension of solid or liquid metals. It may be negligible, but not as regards the phase rule, which must count as units every phase which exists, no matter how weak it may be. Invariant systems are composed of a definite number of phases, independently of the existence or absence of the gaseous phase which is only realised in systems comprising condensation. Invariant systems become univariant by the complete condensation of the gaseous phase, and such univariant systems can give rise to new invariant systems, when, under considerable pressures, they are forced into equilibrium.

L. E. Benson, *Nitrogenisation of Iron and Steel by Sodium Nitrate.* (This Journal, p. 95.)

J. J. Curran, "*Modification*" *of Aluminium-Silicon Alloys* (Chemical and Metallurgical Engineering, August 23, 1922, vol. 27, pp. 360–361). Aluminium-silicon alloys may possess either one of two entirely dissimilar structures, termed respectively "normal" and "modified" or "refined." It would appear from the work of previous investigators that the modified structure results only when alkali fluorides enter into the preparation of the alloy. It seemed probable, therefore, that alkali chlorides would lead to similar appearances and experiments were undertaken to synthesise a modified alloy on these lines. The experiments proved successful and led to the conclusion that in this case the modified structure was caused by the absorption of sodium to form a ternary alloy. In alloys for many purposes resistance to corrosion is a very important property, and it might be expected that modified alloys would be inferior in this respect to normal alloys owing to the presence of alkali metal.

Spectrographic Analysis.—W. F. Meggers, C. C. Kiess, and F. J. Stimson, *Practical Spectrographic Analysis* (U.S. Bureau of Standards, Scientific Paper No. 443, 1922). A brief review is given of various methods which have been proposed for chemical analyses by means of the spectrum, followed by a detailed description of the principles, the apparatus, and procedure employed in making quantitative analyses from the spectra of condensed sparks. The principle is based on the well-known fact that if the spectra of flames, arcs, or sparks are examined either visually or photographically, it is noticed that with the diminution of an element in a mixture its spectrum becomes more simplified, more and more lines disappear, so that in general only one extremely sensitive line remains when a minute trace of the element is present. The spectrographic method of analysis is especially sensitive and useful in cases where small quantities of samples or impurities are to be tested. It can therefore be used to advantage in supplementing assays or the wet methods of chemical analysis.

Stainless Steels.—K. Daeves, *Rustless Steels* (Stahl und Eisen, August 24, 1922, vol. 42, pp. 1315–1320). It is contended that the historical record of the development of rustless or stainless steel shows that neither Brearley nor Haynes was the original inventor of stainless steel, but that a 20 per cent. rustless chromium steel alloy was first produced by Strauss and Maurer in 1909, and their experiments led to the taking out of a patent in October 1912 by Krupp for a rustless steel for turbine blades, cutlery, and other objects. The composition, heat treatment, and tensile properties of chromium steel containing 11 to 20 per cent. of chromium are discussed. The uses of it could be very greatly extended if the cost of manufacture of carbon-free ferrochrome could be brought down. A bibliography of literature on stainless steel and iron-chromium alloys is given at the end of the article.

H. J. French, *Stainless Steel at High Temperatures* (Iron Age, August 17, 1922, vol. 110, pp. 404–405). Two series of tensile tests were made throughout the range 20° to 550° C. The steel was first oil-quenched from either 955° or 1150° C., and subsequently tempered at 675° C. The first of these methods of hardening produced excellent combinations of strength and ductility whether or not the steel is subsequently tempered, while maximum hardness is produced with moderately rapid cooling from the range around 1150° C. The higher quenching temperature (1150° C.) produces metal generally about 10,000 lbs. per square inch, stronger at higher temperatures than that similarly quenched from 955° C. However, this small increase is obtained at the expense of a very large proportion of the ductility.

Elongation decreased about half and reduction of area dropped from values between 60 and 80 per cent. to less than 20 per cent. throughout the entire range considered. An even more striking illustration of the deleterious effects of the high temperature quench is shown in the examination of fractures. Coarsely crystalline breaks are obtained with little or no elongation such as is observed in the series first quenched from 955° C. The latter likewise show much finer structures. Unlike carbon steels which are strongest and at the same time most brittle around "blue-heat" (300° C.), the strength of stainless steel decreases steadily with rise in temperature. However, comparison with the properties of carbon steels in normalised, cold-rolled, and quenched and tempered conditions shows some decided advantages for stainless steel.

H. Hubert, *Stainless Steel, its Discovery, Composition, Properties, Methods of Working and Applications* (Revue Universelle des Mines, April 1, 1921, vol. 13, Series 6, pp. 19–28). A review, as its title indicates, covering the whole ground in relation to stainless steel, and describing its chief characteristics and mechanical and physical behaviour.

H. S. Rawdon and A. I. Krynitsky, *Resistance to Corrosion of Various Types of Chromium Steels* (Chemical and Metallurgical Engineering, July 26, 1922, vol. 27, pp. 171–173). A series of chromium steels containing from 3·9 to 13·3 per cent. of chromium and traces only of nickel were subjected to corrosive attack by dilute hydrochloric acid, and a further series underwent a simulated "weather" test. This consisted in exposing suspended specimens immersed just below the surface of distilled water in an uncovered dish kept near an open window, to secure a constant supply of fresh air. Corrosion in chromium steel was found to consist of attacks in small isolated spots rather than by general tarnishing. This, coupled with the fact that adherent particles of oxide scale accelerated corrosive action, suggests that the presence of inclusions may be the cause. A high chromium steel which contained high silicon as well (0·7), exhibited superior resistance to corrosion. No single type of non-corrodible steel would appear to withstand every special corrosive influence; some are suitable to withstand acid attack, and some are more suitable for withstanding atmospheric action.

Chromium Steels and Alloys (Chemical and Metallurgical Engineering, September 6, 1922, vol. 27, p. 483). A short general review of the properties and uses of chromium steels,

H. Whitaker, *Stainless Steel and Rustless Iron* (Ironmonger, May 13, 1922, vol. 175, p. 106). A general account of the properties and composition of rustless steel and methods of coating steel articles.

Corrosion and Protection of Iron and Steel.—Sir R. Hadfield, *The Corrosion of Iron and Steel* (Proceedings of the Royal Society, Series A, September 1922, vol. 101, pp. 472–486). Experiments made in

America, in Germany, and in this country have shown that mild steel containing a small percentage of copper has proved superior in resisting corrosion as compared with ordinary steels. Comparative tests were carried out by the author on wrought iron, Swedish charcoal iron, Armco iron, mild steel with varying percentages of manganese, mild steels with 0·6 and with 2·18 per cent. of copper, nickel steels, and non-rusting steel with 13·57 per cent. of chromium. Specimens of American mild steels containing a low percentage of copper were also received from D. M. Buck, and were exposed simultaneously at Hathersage, eleven miles from Sheffield, and at Attercliffe in the manufacturing district of Sheffield. Sea-water tests were also made. The copper steels were rather less corroded than the ordinary steel, especially in the more corrosive atmosphere at Attercliffe. In sea-water the ordinary steel corrodes more rapidly at first, but subsequently the rate of corrosion for both materials slows up, indicating a certain degree of self-protective action, which is more pronounced for ordinary steel. Tested in sulphuric acid, copper steel is far more resistant against attack than ordinary steel, the relative rates of corrosion being as one to nine. In the case of base metal exposed to the atmosphere, a small copper content of, say, 0·16 to 0·25 per cent. is beneficial, but no tests have yet been made which show that coated metal would be benefited by a copper content.

B. D. Saklatwalla, *Adsorption a Criterion of Corrosion* (Chemical and Metallurgical Engineering, September 27, 1922, vol. 27, p. 647). The condensation of gases on the surface of metals would tend to impart surface activities that would depend upon the degree of adsorption. A definite relationship might therefore exist between corrosion and adsorption and measurements of the one property serve to indicate the behaviour in regard to the other. The study of immersion corrosion, from the adsorption point of view, would then resolve itself into a study of the dissolved gases.

R. E. Wilson, *The Mechanism of the Corrosion of Iron and Steel in Natural Waters and the Calculation of Specific Rates of Corrosion* (Paper read before the Pittsburgh Meeting of the American Chemical Society: Chemical and Metallurgical Engineering, September 20, 1922, vol. 27, pp. 592–593). Three reactions are stated to be involved: (1) The action of the hydrogen-ion on the iron to form ferrous ions and a kind of atomic hydrogen, neither gaseous nor yet ionic; (2) the formation of water from the atomic hydrogen with dissolved oxygen; and (3) the formation of gaseous hydrogen from atomic hydrogen.

F. N. Speller and V. V. Kendall (*ibid.*), dealt respectively with the corrosion of iron pipe and with the effect of velocity on corrosion.

N. B. Pilling and R. E. Bedworth, *Mechanism of Metallic Oxidation at High Temperatures* (Paper read before the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, June 1922: Chemical and Metallurgical Engineering, July 12, 1922, vol. 27, pp. 72–74). In some cases an enveloping oxide layer may impede further oxidation; in others it may, if porous, increase it. The resulting action depends on the relative metallic and oxide densities. The critical density ratio is $\frac{Wd}{wD}$, when W and w are the molecular and formula weights of oxide formed and metal respectively, and D the density of the oxide formed, d being the density of the metal. A cellular oxide structure results when this ratio is less than unity, and solid crystalline oxide when it exceeds unity. The way in which an oxide layer limits the rate of oxidation is by resisting transmission of oxygen, this resistance being proportional to its thickness. Transmission is effected by actual solution of oxygen in the oxide, diffusion occurring to the inside surface. Critical oxygen pressure bears a close relation to maximum oxygen solubility, and the way in which oxidation rates change with temperature changes is equivalent to the temperature change in the diffusivity of oxygen through oxide as the corresponding change in oxygen solubility appears to be slight.

D. M. Strickland, *Corrosion of Iron and Steel: Influence of Molecular Concentration on Immersion-Test Investigations* (Chemical and Metallurgical Engineering, June 21, 1922, vol. 26, pp. 1165–1169). The author draws attention to the reliability of immersion tests when carefully conducted, not only pointing out the necessity of properly interpreting the influence of solution molecular concentration, but also describing an immersion test method where the variations in solution strength are reduced to a minimum.

W. J. Huff, *Corrosion under Oil Films, with Special Reference to the Cause and Prevention of the After-Corrosion of Firearms* (United States Bureau of Mines, 1922, Technical Paper 188). A review of the literature shows much confusion in the theories involved in the after-corrosion of firearms, and much divergence in the practices recommended for prevention. The report describes a critical laboratory study of the problem, comprising the exposure of fired rifles and fouled barrel sections to known humidities, the chemical examination of the corrosive residue, the use of special ammunition, and the analysis and testing of many "nitrosolvents" and other compositions recommended as preventives.

F. A. Fahrenwald, *The Development of Non-Corrodible Gun Barrels* (Transactions of the Canadian Institute of Mining and Metallurgy, 1921, vol. 24, pp. 196–218). The paper considers briefly the materials used in the manufacture of firearms and outlines the nature of corrosion in gun-barrels. Objections to present-day gun steels are pointed out, and a number of alloys are suggested as ideal materials for the manufacture of gun-barrels.

J. W. Shipley, *Corrosion of Cast Iron and Lead Pipes in Alkaline Soils* (Journal of Society of Chemical Industry, September 30, 1922, vol. 41, pp. 311–316 T). The report relates to corrosive destruction of underground pipes in certain districts in Western Canada. Breaks in the cast iron water-mains within the city of Winnipeg have frequently occurred, and examination shows the characteristic graphitic softening clear through the pipe, and as the softening is produced alike by soil salt solutions or by stray electric currents, it is difficult to determine to which agent the damage can be attributed. An investigation of the effect of soil salts has proved that the corrosion due to these is of the graphitic softening type, and that magnesium salts, in particular magnesium sulphate, are the most effective in producing corrosion. The presence of calcium sulphate in a limy silt soil gives a slight acidity to the ground waters, which promotes autocorrosion. The composition of the metal, the nature of the soil, and the movement of the ground waters are the most important factors producing soil corrosion.

C. A. Suckan, *Corrosion as affecting Boiler-House Efficiency* (Fuel Economy Review, May 1922, vol. 2, pp. 28–30). The author deals with the limitation and elimination of corrosion in boiler plants. The necessity of absolute cleanliness in the boiler house is emphasised.

R. R. Matthews and P. A. Crosby, *Corrosion of Petroleum Refining Equipment* (Paper read before the American Chemical Society, April 5, 1922: Chemical and Metallurgical Engineering, June 14, 1922, vol. 26, pp. 1119–1120). In refining petroleum in pipe stills hydrochloric acid is formed as a result of the hydrolysis of the magnesium chloride in the brine associated with the petroleum. This causes rapid corrosion wherever the acid vapours condense. The author presents further evidence of the corrosion caused by hydrochloric acid, and it is shown that this corrosion is not confined to refineries using the pipe still, but is also noted in installations where shell stills are used. Experience has shown that ammonia introduced into the vapour fractionating system of pipe stills is the best combative agent thus far found for reducing the corrosive effect of the hydrochloric acid. In addition, it no doubt neutralises organic acids which might aid corrosion.

H. L. Olin and R. E. Wilkin, *The Effect of Bomb Corrosion on the Accuracy of Calorimetric Determinations* (Chemical and Metallurgical Engineering, April 12, 1922, vol. 26, pp. 694–696). The author criticises the use of nickel or any other metal so slightly resistant to corrosion as nickel for use as linings in calorimeter bombs. The heat effect of corrosion of the nickel-lined combustion bomb showed in the case of coals with 4·25 per cent. of sulphur content errors as high as 290 B.Th.U. or 2·47 per cent.

L. McCulloch, *Experiments with Sherardising* (Paper read before the American Institute of Mining and Metallurgical Engineers, New York Meeting, February 1922, pp. 4). The brittle iron-zinc alloy coating produced by sherardising is exceedingly valuable as a protective coating. The best mode of carrying it out with zinc dusts is described. The coating contains on an average 6 per cent. of iron, but the presence of iron in the dust lowers the rate of deposition and necessitates the employment of higher temperatures. For testing sherardised coating the Preece or copper-sulphate test is recommended.

J. D. Keller, *Heat Transmission in the Hot Galvanising Process* (Blast-Furnace and Steel Plant, vol. 10, July, August, 1922, pp. 371–373, 407–411). Conditions of heat transmission in the hot galvanising of iron and steel sheets have been very little studied. The speeds at which sheets of various thicknesses should be passed through the zinc bath have generally been determined simply by trial and retrial, the controlling factors being little understood. The author attempts to explain the thermal factors of the process and, on the basis of the factor of heat transmission, calculates how the rate of motion of the sheets through the bath should vary with their thickness. From the rate of transfer of heat from the bath to the sheet the speeds of passing through the bath corresponding to various gauges and thicknesses have been calculated as follows:

Gauge.	Thickness. Inches.	Greatest permissible Speed of Travel. Feet per Minute.	Time for Surface to reach Galvanising Temperature. Seconds.
24	0·025	35·0	6·9
22	0·0312	15·6	16
20	0·0375	10·0	24
18	0·050	5·9	41
16	0·0625	4·1	60

A factor of even greater importance than the speed of galvanising is the production of a coating of just the right thickness. This depends very largely upon the viscosity of the liquid, and upon the speed at which the sheet is drawn out of the bath. Definite figures as to viscosity of liquid zinc or its variation with temperature are not obtainable, but beyond question it, in common with mercury and most other liquids, become less viscous as the temperature is increased. In other words, raising the temperature of the bath tends to produce a thinner coating. On the contrary, increasing the speed tends to give a thicker coating, for two reasons: First, the shearing forces acting to thin down the liquid zinc film on the sheet, as it leaves the bath, are practically constant in magnitude, whereas the time interval in which they can act decreases as the speed is raised. This effect, which is well known in galvanising practice, can be demonstrated very clearly by simple and even crude experiments with other viscous liquids such as syrup or heavy oils. Second, the determining viscosity is not that of the main body of the bath, but that of the liquid very near to the sheet surface. After the solid film has melted off, as previously described, the temperature of the sheet, and of the zinc in immediate contact with it, steadily approaches that of the main body of the bath. But if the sheet is relatively thick and the velocity high, the temperature may not have risen much above the fusion point by the time the sheet reaches the exit rolls. Thus, in spite of the high temperature of the bath, the zinc near the sheet surface, when drawn into these rolls, may be quite viscous, producing a thick coating.

R. G. Skerrett, *Protective Coatings of Sprayed Metal* (Iron Age, August 3, 1922, vol. 110, pp. 286–287). The developments with the Schoop metal spraying process are dealt with. The electro-pistol is a late evolution of the process. The intense heat of the arc makes it practicable to deal with such refractory metals as molybdenum and wolfram.

C. Coffinger, *Manufacture and Properties of Titanium White* (Chimie et Industrie, April 1922, vol. 7, pp. 651–661). Titanium white is superseding lead, zinc, and lithopone pigments, having superior protective and covering properties. It is made in the United States, in Norway, and in France. The various stages of manufacture are described and details given of the properties and applications of the finished product.

R. R. Danielson and H. P. Reinecker, *Wet Process Enamels for Cast Iron* (Bureau of Standards, Washington: Journal of American Ceramic Society, October 1922, vol. 5, pp. 647–669). The wet process of enamelling cast iron has become of great importance, particularly in the stove industry within the last few years, due to the fact that small castings for stoves can be handled at less cost, less skilled labour is required for manipulation, and the method lends itself readily to the enamelling of irregularly shaped castings. Two types of wet process cast iron enamels are used, a two or three coat process using a ground coat and a one or two coat process without the use of a ground coat. The paper deals chiefly with enamels used in connection with a ground coat and particularly with the development of white enamels. The composition of the coats is given, and the method of preparing them and carrying out the enamelling process is described.

B. T. Sweely, *Relation of Composition to Thermal Shock in Steel Enamels* (Journal of the American Ceramic Society, May 1922, vol. 5, pp. 263–265). In suddenly cooling a hot piece of enamel ware, especially what is known as three coat ware, there is an appreciable lag in temperature drop as between the enamel and the steel. The outer layer of enamel may be at the water temperature while the steel and first coat are still very hot. The author proposes to increase the coefficient of expansion of the ground coat as much as possible, in order to have as much contraction as possible over the temperature interval occasioned by the loss of heat through the outer coating when the piece is immersed in the cooling medium. Trials made with first coats of different coefficients of expansion proved that his theory was correct. The composition of the coatings so far experimented with is stated and the work is being continued.

W. S. Scott, *The Development of Industrial Electric Heating for Low Temperature Enamelling* (Paper read before the American Electrochemical Society, September 1922). The development in the use of electricity for the heating of enamelling ovens is described. When electrically heated ovens first came into use, gas ovens were being operated at temperatures from 149° to 176° C., and the baking period was three to four hours. With electric ovens the baking period was reduced to less than one-half, and with enamels baking at 232° C. the baking period was reduced to one hour and in some cases to thirty minutes.

S. R. Gerber, *Hot Tinning* (Metal Industry, April 21, 28, 1922, vol. 20, pp. 369–371, 396). The article gives an account of the reorganisation of a department in a tinplate works for tinning steel cans.

Electrolytic Iron.—D. R. Kellogg, *Electrolytic Deposition of Iron for Building up Worn or Undersized Parts* (Paper read before the American Institute of Mining and Metallurgical Engineers, New York Meeting, February 1922, pp. 6). Results obtained in work of this nature during the war is described. The process employed was Thomas' method, the work to be repaired being the cathode, and an alkaline bath being used with a current density of 3 to 5 amperes per square inch. Smooth, tough, and adherent coats were obtained, and no sign of stripping was observed, even when test-rods were bent in various ways. Brittleness can be removed by heating for a short time at 300° to 400° C.

G. F. McMahon, *The Manufacture of Electrolytic Iron* (Chemical and Metallurgical Engineering, April 5, 1922, vol. 26, pp. 639–641). The design of a plant for the manufacture of electrolytic iron on a commercial scale is described, and the effect of composition, temperature, and circulation of the electrolyte upon the composition of the deposited metal is discussed.

N. B. Pilling, *Effect of Heat Treatment on the Hardness and Microstructure of Electrolytically Deposited Iron* (Paper read before the American Electrochemical Society, September 1922). The author has studied the physical changes accompanying the annealing of pure electrolytically deposited (cathode) iron. The initial effect of annealing is a very marked hardening, reaching a maximum at an annealing temperature of 300° to 400° C. The corresponding scleroscope hardness number is 45. At the same time the initial brittleness is removed. Annealing at higher temperatures results in progressive softening, consummated above the A3 temperature 900° C. Microstructural changes and the rate of decomposition of the unstable iron-hydrogen compound are discussed in relation to the hardness changes.

R. P. Neville and J. R. Cain, *The Preparation and the Mechanical Properties of Vacuum-Fused Alloys of Electrolytic Iron with Carbon and Manganese* (Paper read before the American Electrochemical Society, September 1922). Alloys with negligible amounts of impurities were prepared by fusion *in vacuo* in crucibles of magnesia.

The compositions were so chosen as to bring out the effects on pure iron of additions of small amounts of carbon, manganese, and carbon and manganese together. The ranges in chemical composition of the alloys were from 0 to 1·6 per cent. carbon and 0 to 1·6 per cent. manganese. In amounts below approximately 1 per cent., the ultimate strengths of the alloys were increased by carbon. The ratio of this strengthening effect to carbon content was not constant, but was within the limits of 875 and 1150 lbs. per square inch for each 0·01 per cent. carbon between the limits of 0 and 0·70 per cent. This strengthening effect was greater in the alloys of higher manganese contents. An approximate average of the rate was 1000 lbs. per square inch for each 0·01 per cent. carbon. Manganese increased the ultimate strengths of the alloys only slightly, particularly with small amounts of carbon present. Expressed quantitatively, this rate of increase was about 90 to 250 lbs. per square inch for each 0·01 per cent. manganese. The effects of manganese and carbon on the mechanical properties of the alloys were each influenced by the other.

W. E. Hughes, *Electro-Deposited Iron and Effect of Acid* (Transactions of the Faraday Society, 1922, vol. 17, Part 2). The author gives details of the method of electro-deposition, and describes the microstructure of the deposit.

Laboratories and Laboratory Equipment.—*National Physical Laboratory, Report for the Year* 1921. Work in the laboratory on iron and steel has been devoted mainly to the further investigation of the constitution of the iron-nickel carbon alloys, the iron-phosphorus alloys, and to the determination of the temperature of melting in the iron-carbon system. For this latter purpose an electrical method, first developed in connection with the study of the constitution of the aluminium-copper-nickel system, is being successfully applied. A considerable amount of investigatory test work has been carried out in relation to failure of iron and steel, particularly the cracking of boiler plates around rivet-holes. The preparation, in conjunction with the Iron and Steel Institute, of chemically standardised samples of accurately determined composition has further progressed, and a number of standards are now ready for sale.

A new Metallographic Institute was formally inaugurated in Stockholm on June 1. It is financed by contributions from the leading manufacturers, in co-operation with the Jernkontoret, and suitable premises have been given by the Government. Professor Carl Benedicks has been appointed director, and the laboratories have been very efficiently equipped under his superintendence (Chemical and Metallurgical Engineering, July 5, 1922, vol. 27, p. 38).

The Reichert Metallurgical Microscope (Foundry Trade Journal, September 21, 1922, vol. 26, pp. 241–244). A detailed illustrated description is given of this microscope, which is constructed on the Le Chatelier principle.

CHEMICAL ANALYSIS.

Analysis of Iron and Steel.—A. Travers, *Methods of Estimating Carbon in Iron and Steel* (Chimie et Industrie, January, March 1922, vol. 7, pp. 3–12, 442–451). A review of the three leading modes of carbon determination—(1) by chromic acid combustion either with previous separation of the iron or without, (2) by the Eggertz method, and (3) by direct combustion in a stream of oxygen. The precautions needed to secure accuracy and the sources of error in each type of operation are discussed.

W. Kuebler, *Simple, Foolproof Carbon Combustion Apparatus* (Chemical and Metallurgical Engineering, July 5, 1922, vol. 27, p. 30). A disposition of apparatus employing zirconia boats and 90-mesh R.R. alundum bed, with a Davis-Bournonville gauge on the oxygen supply, set at 200 to 250 bubbles per minute. Once set, this gauge requires no further attention until the tank is empty. Renewals of the pre-purifying train are made about every six months, and of the zinc and calcium chloride tubes every month.

G. Batta and H. Thyssen, *Determination of Carbon in Cast Iron and Steel by the Corleis Apparatus* (Bulletin de la Société Chimique de Belgique, 1922, vol. 31, pp. 112–117). A number of tests have been carried out with a view to finding a standard method for the estimation of carbon in cast iron and steel.

N. D. Ridsdale, *Phosphorus in Hæmatite Iron* (Chemical News, June 23, 1922, vol. 124, pp. 370–372). A method is described for the rapid determination of phosphorus in hæmatite iron containing up to 0·2 per cent. of phosphorus, 0·5 per cent. titanium, and 0·15 per cent. of arsenic. The principle of the method is identical with that of the "Concentration" method. In outline it consists of precipitating the phosphorus in the presence of graphite, &c., with a large excess of nitromolybdate, in a very concentrated solution, in order to overcome the retarding influence of titanium; then redissolving this precipitate, which is more or less contaminated with arsenic, silica, &c., through the filter and purifying it by reprecipitation.

A. Marinot, *Determination of Sulphur in Iron and Steel* (Annales de Chimie Analytique et de Chimie Appliquée, 1922, vol. 4, pp. 5–6). The method described is similar to the iodometric method.

A. Eder, *The Determination of Cobalt in Steel* (Chemiker Zeitung, 1922, vol. 46, p. 430).

W. M. Thornton, jun., *The Estimation of Copper and Iron in the Presence of each Other* (Journal of the American Chemical Society, May 1922, vol. 44, pp. 998–1001). A differential volumetric process has been worked out for the estimation of both copper and iron in admixture, which depends upon the following principles: (1) The two metals, in the form of their sulphates, may be titrated in the presence of a soluble thiocyanate with a standard titanous sulphate; the reading corresponds to the sum of the copper and the iron. (2) The coagulated precipitate of cuprous thiocyanate produced in the first titration may be completely removed by filtration. (3) The small amount of ferric sulphate formed as the result of atmospheric oxidation may be reduced to the ferrous condition by the addition of an extra portion of titanous sulphate. (4) The thiocyanate may be rendered inactive toward permanganate by the introduction of silver nitrate in excess, whereupon the titration for iron may be carried out notwithstanding the presence of silver thiocyanate. (5) The titanium trisulphate must be tested for iron and the proper correction applied in case an appreciable quantity is found.

A. S. Townsend, *Rapid Methods for the Determination of Chromium in Steel* (Forging and Heat-Treating, July 1922, vol. 8, pp. 304–308). The author describes the various methods recommended by different authorities for the determination of chromium in steel, and gives a bibliography of literature descriptive of all the rapid methods that have been proposed.

W. Hild, *Rapid Method for the Determination of Chromium in Nickel-Chromium Steels* (Chemiker Zeitung, 1922, vol. 46, pp. 702–703). The sample of steel is dissolved in nitric acid and the solution evaporated with sulphuric acid. The chromic sulphate is oxidised to chromic acid with an excess of potassium permanganate, and the excess destroyed by heating with manganese sulphate. The filtered solution is treated with an excess of standard ferrous sulphate and finally titrated with permanganate. As a control the iron may be removed from a chloric solution by means of ether, the chromium precipitated with ammonia, the precipitate dissolved in sulphuric acid, and the assay finished as above.

L. Losana and E. Carozzi, *The Determination of Chromium in Steel* (Giornale di Chimica Industriale ed Applicata, May 1922, vol. 4, pp. 197–200). A comparison of gravimetric and volumetric methods of estimating chromium and a discussion of their relative accuracy is given. The processes described include gravimetric precipitation of chromic trioxide direct, and as mercuric and lead chromates, and titration methods using iodine solution, Stead's method, a method used at Terni Steelworks, the peroxide of bismuth method, and the ammonium persulphate methods according to the Philips, Travers, and other modifications.

Nicolardot, Geloso, and Réglade, *The Determination of Manganese by the Knorre Method* (Annales de Chimie Analytique et de Chimie Appliquée, 1922, vol. 4, pp. 69–77, 102–110).

H. Rubricius, *The Determination of Nickel in Steel* (Chemiker Zeitung, 1922, vol. 46, p. 26). Instead of precipitating the nickel with dimethylglyoxime in a neutral tartrate solution containing iron, it is recommended to remove the iron by NH_4OH and precipitate the nickel in the ammoniacal filtrate.

T. Nakazono, *The Use of Amalgams in Volumetric Analysis. I. Determination of Molybdenum, Titanium, and Iron. II. Determination of Vanadium and Uranium* (Journal of the Chemical Society of Japan, 1921, vol. 42, pp. 526–537, 761–768).

L. Losana and E. Carozzi, *The Determination of Titanium in Metallurgical Products* (Giornale di Chimica Industriale ed Applicata, September 1922, vol. 4, pp. 394–396). Some of the difficulties encountered in estimating titanium are pointed out, and the results of the volumetric method are shown, using methylene blue as both an oxidising agent and a titrational colour indicator. Tables are given showing the results as determined on a series of steels and ferro-titanium alloys to which definite predetermined amounts of titanium had been added.

The same authors likewise describe a process for *The Rapid Analysis of Ferro-Tungsten* (Giornale di Chimica Industriale ed Applicata, July 1922, vol. 4, pp. 299–301).

F. E. Lathe, *Analytical Problems in the Metallurgy of Nickel* (Journal of Society of Chemical Industry, August 15, 1922, vol. 41, pp. 270–273 T). The author describes the methods in use in the laboratories of the nickel-smelting plants for the estimation of copper, nickel, cobalt, silica, iron, and sulphur. In selecting the methods employed the requirements as to both speed and accuracy have been mainly kept in view.

A. Kropf, *Colorimetric Determination of Vanadium in Steel* (Zeitschrift für angewandte Chemie, 1922, vol. 35, pp. 366–367). Steel containing vanadium is dissolved in a mixture of sulphuric acid (1 : 5) and phosphoric acid (specific gravity 1·2) in the proportion of 9 parts to 1, and the solution is oxidised with nitric acid (1 : 1). The solution is boiled, cooled, boiled again after adding 1 cubic centimetre of 10 per cent. ammonium persulphate solution, cooled, and 1 cubic centimetre of hydrogen peroxide solution is added and the liquid is diluted to 20 cubic centimetres. The colour is compared with that obtained by adding known amounts of a standard vanadium solution to a synthetic steel solution with approximately the same nickel and chromium content as the test solution, made by dissolving plain carbon steel in the above manner, and the requisite amounts of standard chromium and nickel sulphate solutions.

G. Misson, *Colorimetric Estimation of Vanadium in Steel* (Bulletin de la Société de Chimique de Belgique, 1922, vol. 31, pp. 123–126).

H. Briefs, *The Analytical Chemistry of Vanadium* (Stahl und Eisen, May 18, 1922, vol. 42, pp. 775–778). An investigation is described the object of which was to find a new method for the separation of chromium and vanadium, to discover a method for dispensing with the ether process in examining special steels containing vanadium, and to study the use of cupferron for the precipitation of vanadium. A new method for the separation of chromate and vanadate is described, but the endeavour to find a way of dispensing with the ether process led to no result. Cupferron is suitable for use in analysing ferro-vanadium, and is particularly good for separating vanadium from chromium salts. The process of analysing a chrome-vanadium steel in accordance with the author's modifications is described, involving the use of either the ether process or the barium carbonate process, and subsequently separating the chromium and vanadium either by zinc oxide or cupferron.

P. Klinger, *A Method for Determination of Nitrogen in Steel and Pig Iron and the Part Played by Nitrogen in Metallurgical Processes* (Stahl und Eisen, August 17, 1922, vol. 42, pp. 1290–1296). A general review of the work carried out within recent years by different investigators of the influence of nitrogen and its determination in iron and steel, with a summary of their observations.

H. L. Simons, *Determination of Gases in Metals* (Chemical and Metallurgical Engineering, August 9, 1922, vol. 27, pp. 248–249). The smallness of the amount of gas present in metals is a consideration to be borne in mind in all analytical methods involved. The process described applies to alloys, but not to pure iron and steel, as it is based on the fact that the non-ferrous metals form amalgams with mercury, from which the liberated gases can be pumped off. An illustration of the apparatus used and a description of the method are given.

R. Adam, *Notes on Chemical Standards and their Rôle in the Unification of Methods of Analysis* (Chimie et Industrie, July 1922, vol. 8, pp. 26–37). Commences with the plea for the necessity of fixing a standard of permissible error in commercial analysis, and shows the importance of having chemical standards for checking methods and standard methods as well. The attempts made to standardise methods and to provide standards in America, Great Britain, and France, are described, and reference is made to the standard chemicals supplied by Ridsdale.

Analysis of Ores and Slags.—G. Chaudron and G. Juge-Boirard, *The Determination of Sulphur in Iron Pyrites* (Comptes Rendus, 1922, vol. 174, pp. 683–685). In the determination of sulphur in pyrite by oxidation with aqua regia, when other sulphides, especially those of copper or zinc, are present, the oxidation is attended above 60° by a liberation of free sulphur. The sulphur is completely oxidised if the reaction is allowed to take place in the cold, the only objection to this method being the increased length of time required for oxidation. A 0·5 gramme sample of pyrite ground to 120-mesh requires five to twelve hours for oxidation in the cold by 10 cubic centimetres of aqua regia.

H. D. Buell, *Qualitative Test for Uranium* (Journal of Industrial and Engineering Chemistry, 1922, vol. 14, p. 593). For the determination of uranium in slags or ores a nitric acid solution of the material is prepared with an excess of granulated zinc. When the reaction with the acid has subsided a yellow deposit appears on the zinc if uranium is present. The test is not affected by the presence of gold, platinum, thorium, lead, tungsten, titanium, chromium, mercury, or copper. Iron and vanadium interfere only if present in large quantities, and in that case the spent liquid is removed and the zinc and the deposit are again treated with the nitric acid. The deposit dissolves but reappears when the acid is again exhausted and vanadium and iron remain in solution.

The Analysis of Cupola Slag (Foundry Trade Journal, August 24, 1922, vol. 26, pp. 168–169). A method is described which gives details of a rapid means of separating the constituents of the slag after the latter has been dissolved.

Analysis of Fuel.—R. Lant and E. Lant-Ekl, *The Determination of Sulphur in Coal* (Brennstoff Chemie, 1921, vol. 2, pp. 330–332). By the method described both the combustible sulphur and the sulphur in the ash can be determined.

A. Grounds, *The Analysis of Coke* (Iron and Coal Trades Review, June 30, 1922, vol. 104, p. 977; Foundry Trade Journal, May 25, 1922, vol. 25, pp. 381–382). Methods for the sampling and analysis of coke are given.

Analysis of Gas.—E. W. Blair and T. S. Wheeler, *An Improved Form of Gas Analysis Apparatus* (Journal of Society of Chemical Industry, June 15, 1922, vol. 41, pp. 187–188 T). The apparatus is an improved form of the usual Bone-Wheeler gas analysis apparatus. The chief improvement lies in the use of compressed air and a vacuum to alter the mercury levels in the apparatus. This saves much labour in raising and lowering the mercury frequently through about twice the barometric height. An illustrated description of the apparatus is given.

G. Wollers, *Determination of Carbon Monoxide and Small Quantities of Combustible Gases* (Stahl und Eisen, July 6, 1922, vol. 42, pp. 1050–1055). The author recommends as the most useful method for determining small quantities of carbon monoxide, absorption by means of ammoniacal copper chloride solution. The complete absorption of the carbon monoxide can only be ensured by treating the gas at least twice with the solution and finally again treating it with fresh copper-chloride solution. The absorption capacity of the solution is influenced both by methane and hydrogen.

T. Kaleta, *The Determination of Carbon Monoxide in Blast-Furnace Gas by Combustion* (Chemiker Zeitung, 1922, vol. 46, p. 430). It is recommended first to absorb the carbon dioxide of the gas, mix the residue with an excess of O_2, explode by means of a glowing platinum wire electrically heated, measure the contraction and absorb the carbon dioxide from the carbon monoxide. If it is desired to know the methane content it is necessary to absorb the unused O_2 with phosphorus or with pyrogallol.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

N. T. Belaiew. "*Crystallisation of Metals.*" 8vo, pp. 143. London, 1922: University of London Press, Ltd.

[In the spring of 1922 the author delivered a course of lectures in advanced metallurgy at the Royal School of Mines, which now form the basis of this volume. A preface to the volume has been contributed by Professor H. C. H. Carpenter, in which he writes: "The subject chosen by the author is one both of scientific and industrial importance. On the one hand, metals exhibit certain peculiarities of crystallisation, giving rise, *e.g.*, to characteristic skeleton, dendritic, and arborescent forms, which have been the subject of much study during recent years. Moreover, the investigation of reactions between metallic crystals has probably contributed more to a knowledge of the reactions between substances in the solid condition than has any other branch of physical chemistry. Much light has been thrown on the nature of diffusion in the solid state and on solid solutions themselves. On the other hand, the properties of metals are the properties of metallic crystals, and the behaviour of every metallic article used in the arts and industries depends upon the particular size, arrangement, texture, and composition of the crystals of which it is composed. For the most part these crystals are very small, and require for their investigation a special microscopic technique. This is an important part of the new science known as 'metallography.' Colonel Belaiew, however, has very wisely insisted on the fundamental importance of a knowledge of the macrostructure of metals and alloys, and his lectures illustrate in a particularly striking way the intimate relation between the macrostructure and microstructure of any given alloy as regards its properties."]

Hütte. "*Taschenbuch für Eisenhüttenleute.*" 8vo, pp. 963. Second edition. Berlin, 1922: Verlag von Wilhelm Ernst und Sohn. (Price, cloth bound, 740 marks.)

[A revised and enlarged edition of this well-known work has appeared. A number of new sections have been added, the chief of which deal with the classification of iron ores and iron ore deposits, their composition and leading characteristics; methods of measurement and measuring instruments; fuels, their composition and heat value; architecture; railway engineering; power installations; Diesel engines; sewage purification and other subjects. The original data on iron and steel works, manufacture of iron and steel products, foundry practice, heat treatment, testing of materials, cement manufacture and testing have all been revised and brought up to date. The book comprises a vast store of information in concise form and based upon experience gained in actual practice.]

J. W. Urquhart. "*Steel Thermal Treatment.*" 8vo, pp. 336. London, 1922: Crosby Lockwood & Son. (Price 35s.)

[The author, who has been engaged for many years, in his own workshops, in the production of various steel component parts and tools, has aimed at co-ordinating the work of the laboratory with that of an engineer's hardening department, where the necessity existed of putting into practical use all recent scientific methods employed in the heat treatment of steel. He has now collected and published in book form the results of his experience, and his work is of particular value in showing that, despite the still existing tendency on the part of the so-called practical man to decry the value of scientific metallurgical research and to criticise papers embodying results of such research, as being too academic and possessing no interest for publication by Metallurgical Institutes, the scientific study of the structure and properties of steel and steel alloys and the manner in which they are influenced by treatment, have led to the most remarkable developments, revolutionising practice in the construction of engines, machines and automobiles of all kinds. The author indicates what important advances have been made in these industries by following exact systems in the application of heat, by means of which the physical and mechanical properties of material can be definitely varied at will. The condition of the steel at various stages of heat treatment, chilling, and tempering is depicted by a series of photomicrographs, the study of which affords in itself a liberal education in the treatment of steel and steel alloys.]

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